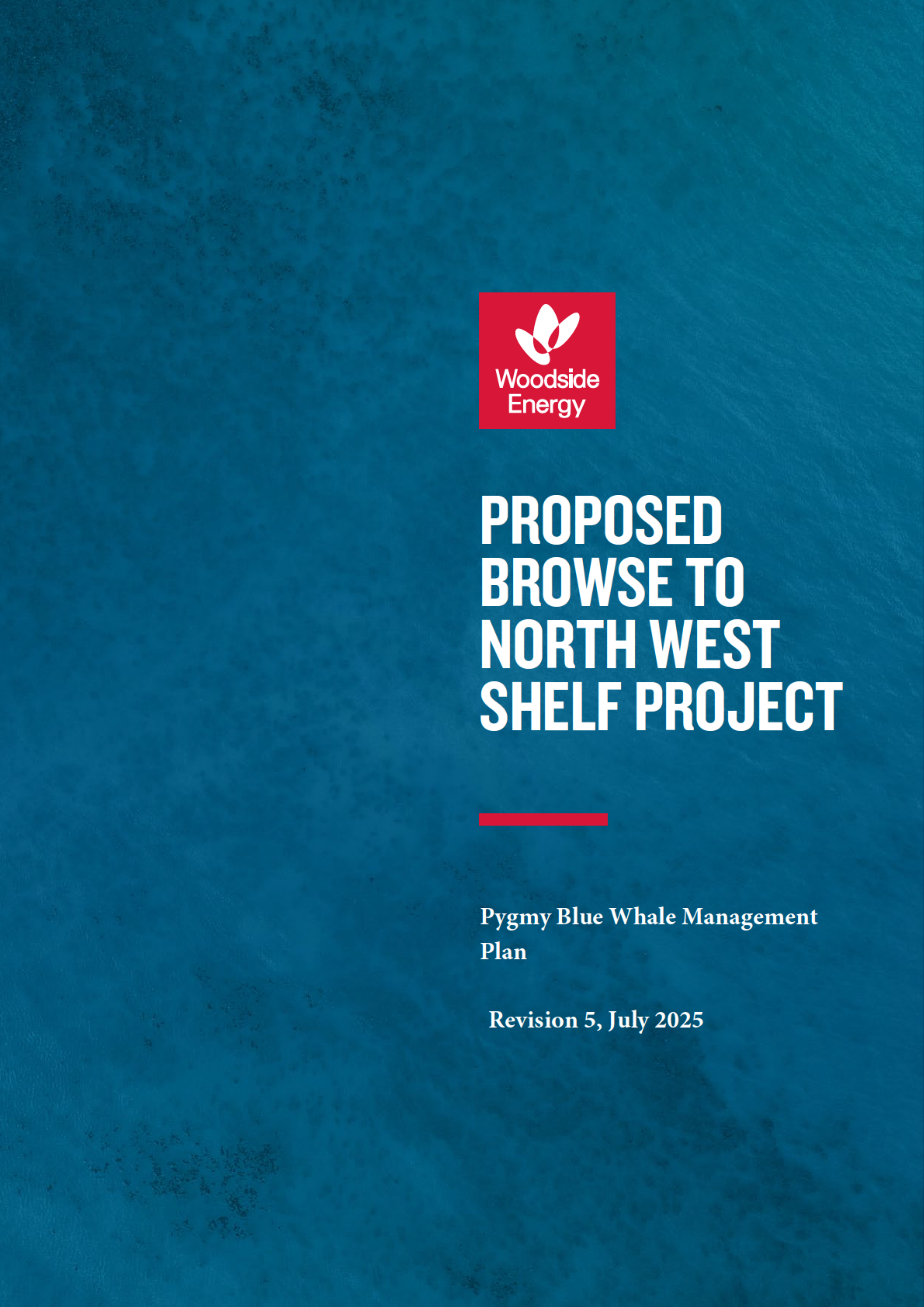

PROPOSED BROWSE TO NORTH WEST SHELF PROJECT

Pygmy Blue Whale Management Plan

Revision 5, July 2025

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

1. EXECUTIVE SUMMARY

Proposal name	Proposed Browse to NWS Project
Proponent name	Woodside Energy Ltd
Ministerial Statement No.	TBC
Purpose of the Environmental Management Plan (EMP)	Provide a Pygmy Blue Whale Management Plan (PBWMP) that outlines how impacts to Pygmy Blue Whales will be managed to meet the project objectives.
Key environmental factor/s, outcome/s and/or objectives	Relevant key environment factors are: • Marine Fauna Relevant matters of environmental significance are: • Listed threatened fauna and ecological communities • Listed migratory species The environmental objectives that are relevant to pygmy blue whales are: • 26 - Undertake the Browse Project in a manner that prevents physical injury to marine fauna (cetaceans, marine turtles, whale sharks, dugongs, seabirds and migratory shorebirds)*. • 27 - Undertake the Browse Project in a manner that will not disrupt the migration and feeding of the East Indian Ocean pygmy blue whale population. • 28 - Undertake the Browse Project in a manner that will not displace the East Indian Ocean pygmy blue whale population from the possible foraging area at Scott Reef. **The scope of this EMP is limited to management of pygmy blue whales.*
Condition clauses	TBC
Key components in the EMP (if applicable)	The structure of the PBWMP is: • Project background and overview (Section 2) • An overview of the purpose of this plan (Section 3) • An overview of the existing knowledge in relation to pygmy blue whales (Section 4) • A description of how the underwater noise emission from the proposed Browse Project have been characterised (Section 5) • An overview of the noise modelling results (Section 5.3) • A detailed overview of the management approach (Section 6) • An overview of the design and management features (Section 8) • An overview of the scientific monitoring program (Section 7) • Framework for Noise Mitigation Plans to be applied during operations (Section 9) • Expected outcomes (Section 10) • Plan review requirements (Section 12)
Proposed construction date	Mid 2020s
EMP required pre-construction?	Yes X No ☐

1.1 Purpose

The purpose of this plan is to outline the management approach that will be implemented as part of the Browse Project, to ensure that impacts from the generation of underwater noise or other pathways are not of a magnitude that could injure or otherwise impact migration or foraging of the East Indian Ocean population of Pygmy Blue Whales.

Woodside has also focussed on demonstrating that all reasonably practicable available underwater noise mitigations have been implemented in alignment to the mitigation hierarchy and describing how adaptive management will be applied in response to new information.

As the Blue Whale is listed as endangered under the EPBC Act, a Conservation Management Plan (the CMP) has been created to minimise the anthropogenic threats to the blue whale with the long-term objective of improving populations so that they are no longer listed as a threatened species under the EPBC Act. This plan outlines how any underwater anthropogenic noise associated with the proposed Browse to NWS Project (Browse) will be managed such that it will not be inconsistent with the Conservation Management Plan (CMP) for the Blue Whale, specifically the requirements of Action A.2.3.

Action Area A.2, Action 3 of the CMP that states that:

> *“anthropogenic noise in biologically important areas (BIAs) will be managed such that any blue whale continues to utilise the area without injury, and is not displaced from a foraging area”*.

Guidance provided by the Australian Government on how activities must have regard to the CMP has been applied to the development of this plan. Woodside considers that the CMP requires the following, which constitutes the definition of an ‘acceptable’ level of impact of residual underwater noise:

- Effective mitigation measures for underwater noise shall be implemented such that no threat of unacceptable impacts to blue whales exist, where unacceptable impacts are considered to be injury or biologically significant behavioural disturbance:
    - Injury is both permanent and temporary hearing impairment (Permanent Threshold Shift and Temporary Threshold Shift) and any other form of physical harm arising from anthropogenic sources of underwater noise.
    - Biologically significant behavioural disturbance can occur where a blue whale is stopped/prevented from foraging or moved on from a foraging area over a sufficient temporal/spatial magnitude to pose a threat to the fitness of the blue whale.

Woodside considers that the Proposal is consistent with the CMP as all underwater noise sources can be managed such that no threat of unacceptable impacts to blue whales exist, noting existing guidance on implementation of the CMP must be considered in context of the overarching recovery objectives for the species.

A detailed overview of each objective of this plan is in **Section 3** and a summary of outcomes is provided in **Section 10**.

Management principles for ensuring prevention of injury from impulsive noise

The spatial and temporal controls presented in this plan ensure that all activities generating potentially injurious impulsive noise will either be inherently eliminated by design or limited. If they are required, they will only occur outside of times/places where pygmy blue whales are likely to be present. A scientific monitoring program will be put in place prior to these activities occurring to provide a thorough understanding of times and places pygmy blue whales are likely to be present in and around the project area. A requirement to monitor for whales will apply to these activities, which can be immediately ceased if a whale is sighted, on a precautionary basis.

Management principles for ensuring for prevention of injury from continuous noise

Modelling indicated that the greatest distance at which a whale may be injured by noise (i.e. due to temporary or permanent hearing impairment) from Browse activities after 24 hours of continuous exposure was 2.1 km. For vessels that are present for longer periods, (i.e. MODUs and Torosa FPSO), these were modelled as generating noise capable of injuring a whale (after 24 hours of continuous exposure) at distances of less than 600 m from the noise source.

Whales at eastern Scott Reef are typically conducting migratory behaviour, typically travelling 2 – 3km/hour, inherently minimising the risk they remain in close proximity to a vessel for sufficient duration to be exposed to possibly injurious noise. As this form of injury only occurs after extended periods of exposure, simulations of whale behaviour were modelled (ANIMAT Modelling) to estimate a more realistic evaluation of injury risk. ANIMAT modelling indicated that for the loudest vessel activity (trunkline installation) 95% of simulations that resulted in injury only occurred where a whale passed within 50 m of the sound source. The probability of a PBW coming to such close proximity of a vessel was considered highly unlikely.

When accounting for exposure duration, there was no risk that whales would be exposed to acoustic injury from MODU or FPSO activities.

Non-migratory behaviours may result in increased residency time and probability of exposure, however these are further managed through controls adopted to prevent disturbance to foraging whales.

Disruption of foraging behaviour

It is recognised that the proposed Browse Project may result in the generation of underwater noise in excess of the recognised behavioural response threshold (120db), which has the potential to disrupt pygmy blue whale foraging behaviour. Accordingly, this plan has considered:

- the time of year the activity will be undertaken and the likelihood of pygmy blue whale foraging in the area of potential overlap of the proposed Browse Project and the Scott Reef possible foraging area (BIA) (summarised in **Section 4**)
- the extent, intensity, and duration of sound exposure within the Scott Reef possible foraging area, including residual and cumulative impacts after the application of controls (summarised in **Section 5**)
- the implementation of any appropriate controls to prevent unacceptable impacts (in accordance with the management framework outlined in **Section 6**.

Best practice management measures in accordance with a precautionary approach have been established within this plan and successful implementation will ensure that, with a high degree of certainty, the anthropogenic noise from the proposed Browse Project will be managed such that any blue whale will be able to continue to utilise the BIA without injury, and no blue whale will be displaced from a foraging area. In this way, the proposed Browse Project will not be inconsistent with the CMP.

A summary of the information within this plan that is provided in support of this conclusion is presented below.

1.2 Existing Knowledge of Pygmy Blue Whale Activity at Scott Reef

Pygmy blue whales are known to migrate on an annual basis through the Scott Reef possible foraging area on their way to and from breeding and feeding grounds within the Banda Sea, Indonesia. The migratory seasons are defined by shoulder and peak periods and exact timings can vary inter-annually.

Woodside considers there is sufficient scientific certainty regarding both the blue whale utilisation of Scott Reef and possible impacts to demonstrate that the Project does not present a credible threat of significant impacts to the EIO PBW population.

Evidence collected to date from a variety of techniques including sampling of zooplankton, pygmy blue whale vocalisation data from passive acoustic monitoring (noise loggers), survey observations (vessel-based and aerial) and satellite tracking suggests that Scott Reef is likely to be of less importance for the East Indian Ocean (EIO) pygmy blue whale population than other defined foraging areas. However, the relative importance of Scott Reef as a foraging area for migrating pygmy blue whales remains unclear and as such the possible foraging area will be managed as a known foraging area and BIA for the purposes of the proposed Browse Project.

In known foraging BIAs such as the Perth Canyon, pygmy blue whales can be observed in predictable annual higher abundance, exhibiting foraging behaviours and have extended residence times albeit in large areas of coastal or offshore waters. These observations, behaviours and residence times are not replicated at or in the vicinity of the Scott Reef possible foraging area, despite dedicated, multi-year studies over an extended period, using multiple survey and sampling techniques.

Across the Scott Reef possible foraging area from west to east, based on the understanding of pygmy blue whale foraging areas and habitat suitability, there is a higher likelihood of prey (krill) availability over the upper slope (with canyon features) habitat to the west of Scott Reef as compared to the featureless, homogeneous seabed habitat of the eastern extent of the BIA. This forms the basis of concluding that the likelihood of foraging by pygmy blue whales while migrating through the BIA is higher for (i) the upper slope habitat in the western extent of the BIA and (ii) potentially the Scott Reef channel as based on the findings reported by Sutton *et al*. (2019).

1.3 Management Approach

The management approach incorporates the following key framework components:

- Apply **Management Measures** (**Section 8**) in accordance with the hierarchy of controls (summarised below), based on scientific monitoring results;
- Conduct **Scientific Monitoring (Section 0)** to provide confidence in the times and locations when blue whale foraging is likely to occur;
- **Avoidance (Section 6.1.1):** Avoid generating noise at times/locations when pygmy blue whale foraging is likely to occur, determined based on pre-operational scientific monitoring;
    - **Minimisation (Section 6.1.2):** Use engineering controls & design to reduce the sound source levels associated with activities, or substitute high noise generating activities with quieter alternatives.
    - **Detection and Mitigation (Section 6.1.3):** Where an activity cannot be eliminated, substituted or reduced such that noise generated is below behavioural response thresholds), apply operational mitigations.
- Apply **Adaptive Management (Section 6.2)** in response to new information to ensure the management measures are appropriately applied;
    - **Avoidance (Section 6.2.1)**: Utilise ongoing operational monitoring program and vessel observations throughout Project Execution to maintain a robust understanding of pygmy blue whale seasonality/foraging area use and update Avoidance periods if required.
- **Minimisation (Section 6.2.2)**: In-field verification of underwater noise sources will be performed on long term infrastructure (FPSO thrusters, well heads) that have underwater noise design limits. If verification monitoring finds these underwater noise levels are exceeded, operational limits will be put in place to return to the design limits.
    - **Detection and Mitigation (Section 6.2.3):** To provide confidence that shutdown zones have been correctly described, in-field verification of key underwater noise sources shall be conducted. Shutdown zones in the relevant Noise Mitigation Plan may be updated if in-field verification finds the underwater noise sources are different to expectations.

The management approach within this plan is aligned with industry best practice, as demonstrated by a review of industry practice in other areas where underwater noise impacts on cetaceans is managed **(Section 6.3)**.

1.4 Underwater Noise Characterisation

Noise (sound power level) estimates for major activities or vessels, including continuous or impulsive noise, are presented (**Section 5**) based on suitable analogues or indicative design data.

The key continuous underwater noise sources are:

- Drilling and Completions **(Section 5.1.1)**
- SURF and FPSO Construction and Installation **(Section 5.1.2)**
- FPSO Operations **(Section 5.1.3)**
- Well Head Operations **(Section 5.1.4)**

The key impulsive underwater noise sources are:

- Driven Piling Activities **(Section 5.2.1)**
- Vertical Seismic Profiling **(Section 5.2.2)**

Sound propagation modelling (**Section 5.3)** has then been performed to estimate the distance (R_{max}) from each activity at which certain noise levels will be received, corresponding to potential injury or behavioural disturbance effect thresholds.

Continuous noise sources range from 161.5 dB re 1 µPa.m for well head choke valve noise (at well centres with up to 7 wells) to 191 dB re 1 µPa.m for the rigid pipelay vessel. These activities were estimated to cause potential behavioural responses from pygmy blue whales at ranges from <500 m to 9.9 km, respectively.

Long-term infrastructure will include design controls to minimise underwater noise, and both original and minimised underwater noise sound power level estimates are provided, accompanied by an explanation of how the mitigations will be applied.

1.5 Scientific Monitoring Program

Scientific monitoring programs will be designed to obtain contemporary data on the relative abundance, seasonality and, movement and behaviour of pygmy blue whales within the possible foraging area at Scott Reef prior to the commencement of operations (refer to **Section 7**).

Ongoing data acquisition is planned to occur throughout the life of the proposed Browse Project, which will be important to monitor any changes the movement and behaviour of pygmy blue whales and confirm sound source levels of project activities.

The key objectives of the pygmy blue whale scientific monitoring program are as follows:

- To verify and further understand the seasonality, residency time, behaviours and relative abundance of the EIO pygmy blue whale population utilising the Scott Reef possible foraging area to ensure spatio-temporal management areas are appropriately defined.
- Identify the habitats within the Scott Reef possible foraging area that are likely to support predictable aggregations of prey (including krill) to ensure spatial management areas are appropriately defined.

Additionally, the following monitoring activities will be put in place in support implementation of this plan:

- Measurement of underwater noise from key activities to verify impact predictions and revise management procedures, if required.

- A technology maturation program to investigate and demonstrate feasibility for technologies to enable real-time detection of pygmy blue whales such as underwater listening stations and/or infra-red detection techniques.

An expert panel will be established to input to the scope and design of the scientific monitoring programs, review findings and decisions leading to changes in the management regime to minimise underwater noise emissions and potential impacts to pygmy blue whales.

1.6 Highlights of Key Management Measures

Design features and activity specific management measures applicable to anthropogenic noise with as incorporated by the hierarchy of controls and spatio-temporal management principles are presented in **Section 6** and include:

Noise from drilling and completions (including phase one and future tiebacks) **(Section 8.1)**

- **Avoidance:** Drilling and completions from a MODU will not occur at times/locations when pygmy blue whales are likely to be foraging.
- **Minimisation:** At Torosa and Brecknock, MODUs will not use DP systems to hold station but instead will be moored.
- **Detection & Mitigation:** Vessels operating in the Scott Reef possible foraging area will be required to implement a Noise Mitigation Plan (NMP), including measures to detect whales; and measures to cease underwater noise sources (use of DP for transit and well hookup, use of PSV DP for MODU resupply, drilling) if a whale is detected within the relevant shut-down zone.

Noise from subsea installation/construction (including phase one and future tiebacks) **(Section 8.2)**:

- **Avoidance:** All subsea installation/construction activities within the possible foraging BIA will not occur at times/locations when pygmy blue whales are likely to be foraging. The only exception is the Torosa FPSO Installation, Mooring and Riser Hookup which is a short term activity occurring at the eastern most boundary of the BIA, the timing of which cannot reasonably be guaranteed to occur at a given time.
- **Detection and Mitigation:** Vessels operating in the Scott Reef possible foraging area will be required to implement an NMP, including measures to detect whales; and measures to cease underwater noise sources (use of DP) if a whale is detected within the relevant shut-down zone.

Noise from permanent operations including FPSO and wellheads **(Section 8.3 & Section 8.4)**:

- **Minimisation:** The Torosa FPSO will be designed with a unique focus on noise minimisation including noise from thrusters and topsides equipment. An independent Classification Society will be engaged throughout the design process to verify that the Torosa FPSO thrusters and machinery are designed to achieve low noise targets and a 'low noise classification' will be sought for the FPSO.
- **Minimisation:** All well head choke valves to be installed within the Torosa field will incorporate measures to reduce noise from choke valves to below underwater noise limit (161.5 dB re 1 μPa·m) for all operational (flow rate, differential pressure) conditions.

Noise from Impulsive Noise Sources **(Section 8.5):**

- **Avoidance:** Impact Piling and VSP will not occur at times/locations where foraging by PBWs is likely to be present
- **Minimisation:** Impact Piling will only be used if other forms of pile installation (including suction piling) are demonstrated not to be feasible.
- **Detection and Mitigation**: Impulsive noise source activities will be required to implement a NMP, including measures to detect whales; and measures to cease underwater noise sources (driven piling, VSP) if a whale is detected within the relevant shut-down zone.

1.7 Magnitude of Residual Underwater Noise

After the application of scientific monitoring outlined in **Section 7**, the management measures outlined in **Section 8** and NMPs outlined in **Section 9**, residual cumulative ensonified areas are quantified in provided in **Section 10.**

For short-term (2 – 4 weeks) construction activities, the largest anticipated ensonified area within the possible foraging BIA at any time is approximately 308km^2 associated with Browse trunkline installation. The management framework outlined in this plan requires that this activity will not be occurring in the possible foraging BIA at times when/where pygmy blue whale foraging is likely to occur.

The only short-term construction activity that may ensonify the possible foraging area at a time/location when pygmy blue whale foraging is likely to occur is FPSO mooring hookup, predicted to ensonify up to 19km^2 (0.2% of the possible foraging area) at the height of the activity (estimated to take 4-6 weeks).

After the initial construction phase, the total areal extent of the Scott Reef possible foraging area ensonified above 120 dB and where no further mitigations based on whale sightings are possible, is reduced to:

- ~1.0 km^2 at sea surface (<0.01% of the possible foraging area) or 3.5 km^2 at seabed (0.03%) during normal operations.
- ~22.4 km^2 at sea surface (~0.17% of the possible foraging area) or 24.8 km^2 (0.19%) at seabed during FPSO condensate offtake (24 hour operation every 2-4 weeks).

1.8 Outcomes

Woodside has conducted an evaluation of the proposed Browse Project against the Blue Whale CMP as part of the primary approvals process under the EPBC Act. As part of this, an evaluation has been undertaken in relation to Action 3 of Action Area A.2 of the CMP which is the pertinent action in relation to this plan.

In the context of the overall size of the Possible Foraging Area (>12,000km^2), it is not objectively credible that highly localised residual underwater noise (described in **Section 11.2**) represents a threat of serious damage to blue whale utilisation of Scott Reef, based on the available scientific information demonstrating limited Pygmy Blue Whale utilisation of Scott Reef for foraging. Nor is it objectively credible that the nature and extent of noise represents a threat of irreversible damage to their ongoing opportunity to forage at Scott Reef/loss of foraging opportunities significant enough to result in reduced population fitness.

While it is credible that an individual foraging PBW that approaches to within very close proximity to Proposal vessels or infrastructure could be disturbed, based on extensive data collected by Woodside, the risk of this occurring is remote. It is not objectively credible to conclude that impacts to individual foraging whales resulting from underwater noise from Proposal activities could manifest in biologically significant behavioural disturbance, or adverse outcomes at the population level.

2. INTRODUCTION CONTEXT, SCOPE AND RATIONALE

2.1 Proposed Browse Project

The Browse hydrocarbon resource is located in the Brecknock, Calliance, and Torosa reservoirs, approximately 425 km north of Broome and approximately 290 km off the Kimberley coastline of Western Australia (WA). These three fields will be collectively referred to as the Browse hydrocarbon resources. Hydrocarbon resources contained in these fields are predominately gas, with contingent resources (2C, 100%) of 13.9 trillion cubic feet (tcf) of dry gas, and approximately 390 million barrels of condensate (Woodside resource estimate).

Woodside Energy Ltd (Woodside) is Operator for and on behalf of the Browse Joint Venture (BJV). The participants in the BJV are:

- Woodside Browse Pty Ltd
- BP Developments Australia Pty Ltd (BP)
- Japan Australia LNG (MIMI Browse) Pty Ltd (MIMI)
- PetroChina International Investment (Australia) Pty Ltd (PetroChina).

The BJV proposes to develop the Browse hydrocarbon resources using two 1,100 million standard cubic feet per day (MMscfd) (annual daily export average) Floating Production Storage and Offloading (FPSO) facilities. The FPSO facilities will be supplied by a subsea production system and will transport gas to existing North West Shelf (NWS) Project infrastructure via a pipeline which will tie in near the existing North Rankin Complex (NRC) in Commonwealth waters (Note: The NRC is owned by the NWS Joint Venture (NWSJV)[1]).

2.2 Project Area

The overall Project Area for the proposed Browse Project comprises:

- the proposed Browse Development Area (in which the Brecknock, Calliance, and Torosa fields, the FPSO facilities and the subsea production systems, including wells, will be located) (**Figure 2-1**)
- the pipeline corridor within which the proposed Browse Trunkline (BTL) and inter-field spur line will be located (**Figure 2-2**).

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[1] The NWSJV comprises six companies: Woodside Energy Ltd. (Operator), BHP Billiton Petroleum (North West Shelf) Pty Ltd, BP Developments Australia Ltd, Chevron Australia Pty Ltd, Japan Australia LNG (MIMI) Pty Ltd, and Shell Australia Pty Ltd. The NWS Joint Venture owns the infrastructure used as part of the North West Shelf Project.

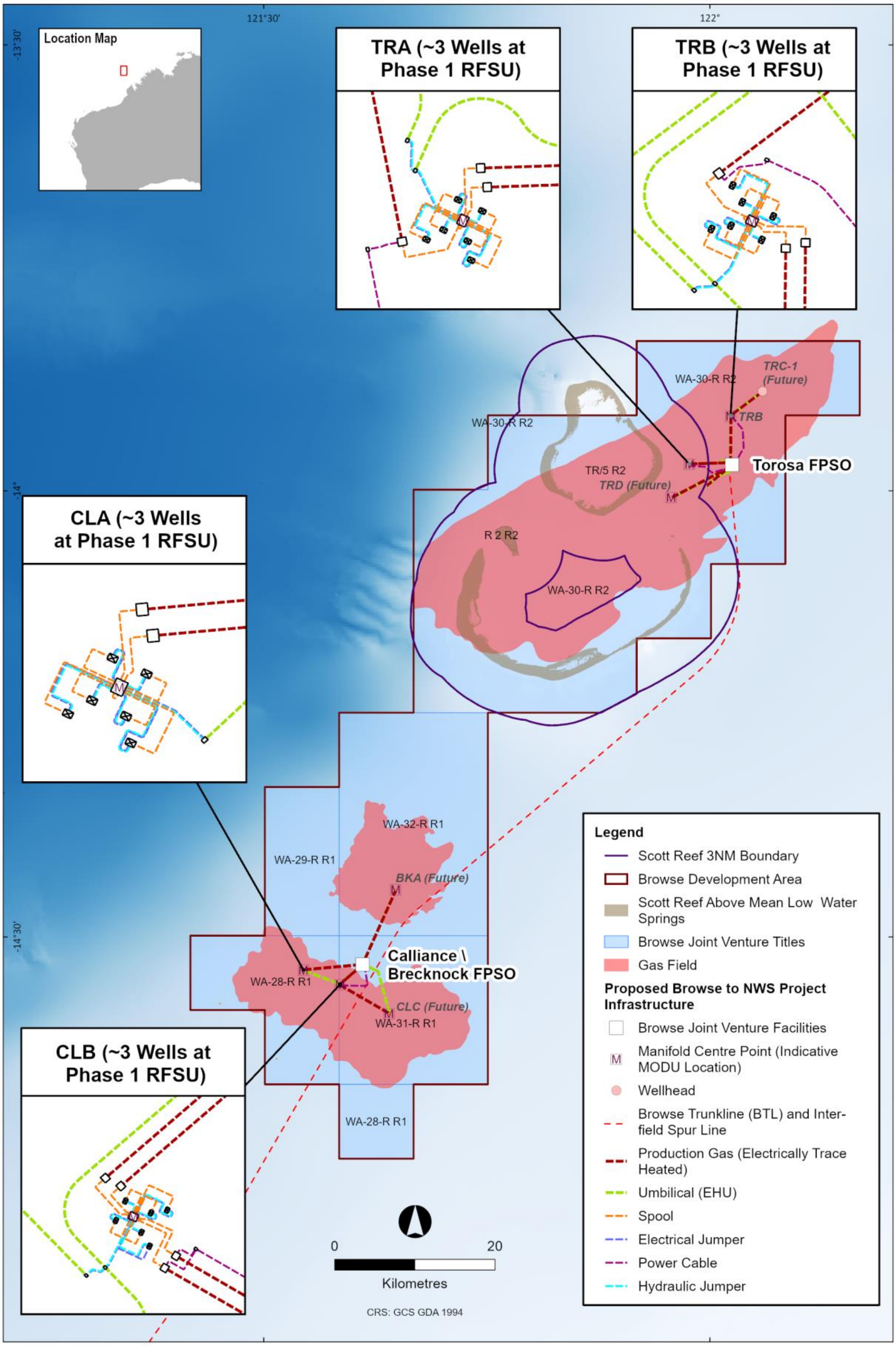

Figure 2-1 Proposed Browse Development Area and notional field layout

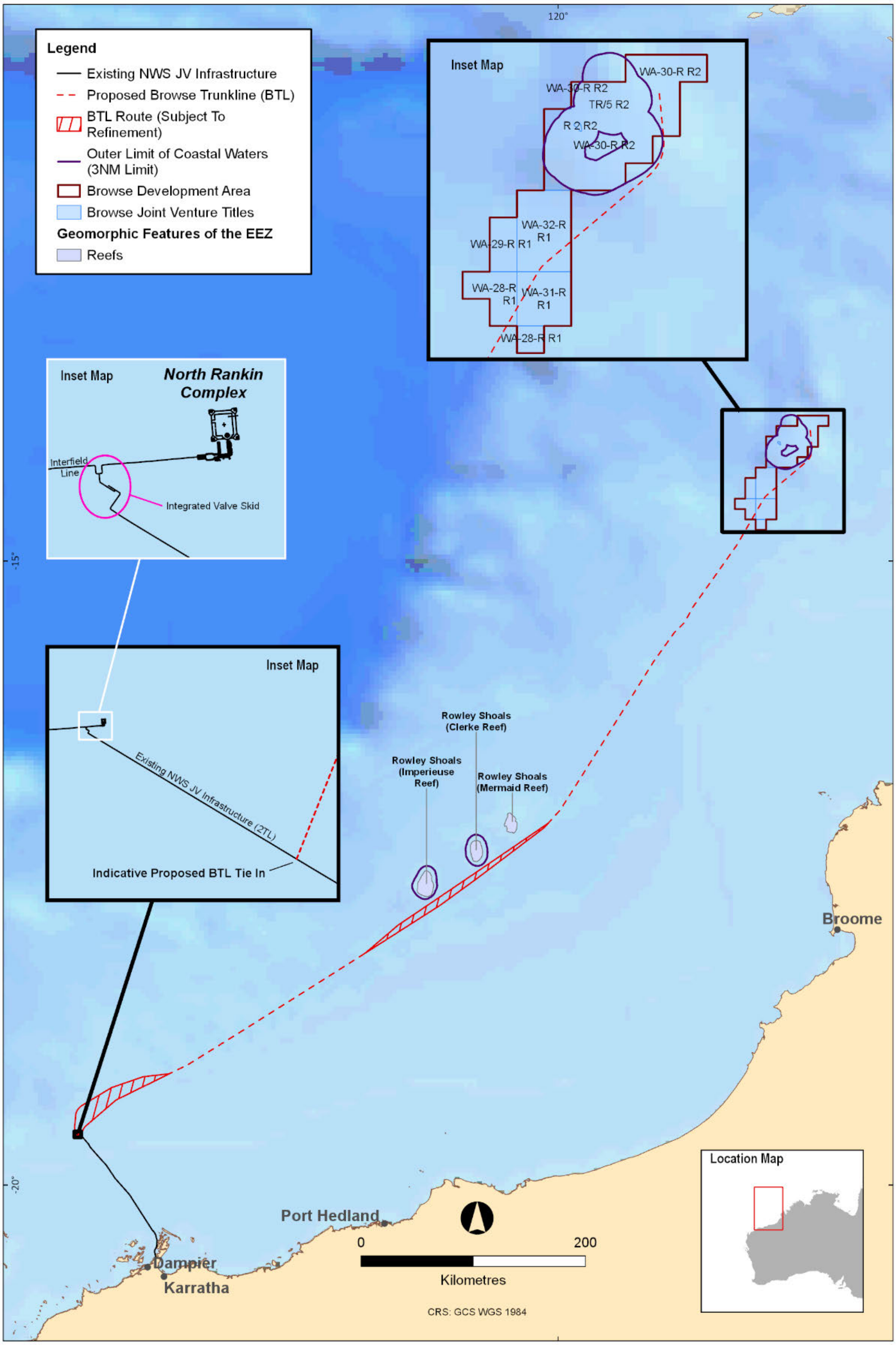

Figure 2-2 Proposed Browse Trunkline (BTL) route

2.3 Project Activities

Activities associated with the proposed Browse Project include:

- Piling for mooring the FPSO facilities, securing the export riser bases and potentially for mooring the MODUs. Suction piling is the most likely option for pile installation, however, depending on the seabed substrate, alternate piling methods such as drilling and cementing or impact piling may be selected. Impact piling is not required for moorings at drill centres.
- Development drilling and completions for the development of up to 50 production wells
- Installation and commissioning of the subsea umbilicals, risers and flowlines (SURF)
- Installation and commissioning of the BTL and inter-field spur line, note that the BTL or IFL do not enter the State Waters boundary.
- Vertical seismic profiling, using air guns with capacity of less than 250 in^3.
- Installation, hook up and commissioning of the FPSO facilities
- Operations including hydrocarbon extraction, gas processing and export and condensate offloading
- Inspection, maintenance, monitoring and repair activities (IMMR) to ensure the integrity of the infrastructure and identify any problems before they present a risk of loss of containment
- Support activities including logistics support, project vessels and helicopters
- Decommissioning in accordance with good oilfield practice and relevant legislation and practice at the time.

A detailed description of the activities associated with the proposed Browse Project is provided in Section 3.7 of the draft EIS/ERD.

For avoidance of doubt, the following activities are not part of the proposed Browse to NWS Project (EPBC Referral 2018/8319 and EP Act Assessment 2191) and not covered by this plan;

- Seismic surveys involving the use of towed streamers of seismic profiling techniques requiring air guns with capacity of >250in^3.

2.4 Construction and Subsea Tie-back Phases and Sequencing

The project will be executed over a number of phases, connecting new wells to the FPSOs to supplement supplies of gas and condensate to the FPSO once production declines from the initial series of wells supplying the FPSO at ‘ready for start up’ (RFSU).

An indicative overview of project activities outlined below, outlining those activities that may generate noise within (or that may propagate to within) the pygmy blue whale possible foraging area at Scott Reef.

Phase One (pre-RFSU) drilling and completion activities

- Drilling and completions of a total of 6 wells, at two drill centres Torosa A (TRA) and Torosa B (TRB) including installation of well heads and xmas trees. Estimated duration is up to three months per well, or 18 months total. Six wells are also drilled at Calliance drill centres (Calliance A (CLA) and Calliance B (CLB)), although underwater noise from Calliance drilling and completion activities are not anticipated to have any impact in the area.

Phase One (pre-RFSU) subsea and construction activities

- Installation and commissioning of the Browse Inter-field Spur Line (IFL) from the Calliance FPSO to the Torosa FPSO.

- Torosa FPSO installation – Piling for mooring the FPSO facilities, installation, hook up and commissioning of the FPSO facilities and installation of risers at the FPSO location.
- Calliance FPSO installation – Piling for the FPSO moorings
- Connection of drill centres to FPSOs – Installation and connection of subsea umbilicals and flowlines between Phase One drill centres and the respective FPSO.

Phase one (pre-RFSU) subsea installation and construction sequencing

The subsea installation and construction sequencing for activities occurring during Phase One are typically consecutive, not concurrent, as certain activities must be completed prior to other activities commencing. This is relevant to this plan in predicting cumulative noise impacts. The consecutive construction sequence at Torosa during Phase one is shown in **Table 2-1**. Once subsea equipment has been installed, a commissioning phase will occur, which continues for a longer duration than construction but will involve less project vessels.

Table 2-1 Indicative proposed construction sequence associated with initial subsea and construction activities associated with development of the Torosa hydrocarbon field (Phase one (pre-RFSU))

Sequencing	Activity	Duration (indicative)	Vessel type(s)
1	Install Browse Inter-field Spur Line from Calliance FPSO to Torosa FPSO	2 -4 weeks	Large rigid pipelay vessel such as *Solitaire or Castorone*. Accompanied by touchdown monitoring vessel.
2	Install flowlines and subsea equipment (e.g. manifolds) including flood, clean gauge and test (FCGT)	One week to reel-lay two flowlines. One month for other subsea equipment.	Reel-lay vessel such as the Deep Energy or Seven Ocean. Construction vessel such as the *Deep Orient* or *Seven Arctic*.
3	Hook-up the Torosa FPSO to the mooring and subsea system	1 month	Approximately four tugs to hold the FPSO in position, construction vessel to lift and connect mooring chains.
4	Hook-up the Torosa FPSO to the subsea system	2 months	Construction vessel such as the *Deep Orient* or *Seven Arctic*.

Additional Project Phases (Phase 2 – 6)

Indicative activities for phases beyond RFSU (Phase One) are outlined in **Table 2-2**, including the indicative timing of when each phase is anticipated to be ready to produce hydrocarbons. Note that there remains uncertainty in the precise timing, ordering and scope for each phase.

It should be noted that while **Table 2-2** shows phasing of future phases at Calliance, drilling and completion activities and other construction activities associated with future phases of Calliance are not anticipated to produce noise received at relevant injury or behavioural response thresholds within the Scott Reef possible foraging area.

Table 2-2 Indicative project phase and relevant activities occurring after initial RFSU (Phase one)

Phase	Indicative Scope	Indicative Activities	Indicative Timing (Post RFSU)
2	Torosa TRD Development, TRA infill	Drilling & Completion, wellhead and xmas tree installation of: 4 x wells TRD 2 x wells TRA Installation of SURF: TRD to Torosa FPSO	4-6 years
3	Brecknock Development, Calliance West Infill	Drilling & Completion, wellhead and x-mas tree installation of: 3 x wells BKA 2 x wells CLB Installation of SURF: BKA to Calliance FPSO	5-8 years
4	Torosa TRC Development, TRA/TRD infill	Drilling & Completion, wellhead and x-mas tree installation of: 1 x well TRC 4 x wells (inclusive of both TRA and TRD) Installation of SURF: TRC to Torosa FPSO	5-9 years
5	Calliance West and Brecknock Infill Campaigns	Drilling & Completion, wellhead and x-mas tree installation of: 3 x wells CLA 1 x well BKA	8-15 years
6	Calliance East Development	Drilling & Completion, wellhead and x-mas tree installation of: 6 x wells CLC Installation of SURF: CLC to Calliance FPSO	11-16 years

Future tieback campaigns

Depending on reservoir outcomes, wells at drill centres not listed above (i.e. TRF & TRH) may be developed and tied back to the Torosa FPSO and additional wells may be drilled at existing drill centres, up to the maximum number of wells (50) planned to occur as part of the Proposal including a maximum of 25 as part of the Torosa field.

The proposed Browse Project requires a maximum of 50 development wells, although even if the median reservoir outcome is achieved, markedly less wells will be developed. There is a 90% probability that less than 46 wells will be required as part of the Proposal, only 21 of which are associated with the Torosa field.

2.5 Key Environmental Factors and Matters of National Environmental Significance

Table 2-3 outlines the Key Environmental Factors and Matters of National Environmental Significance and the relevant impacts and risks.

Table 2-3 Key Environmental Factors and Matters of National Environmental Significance

Key Environmental Factors and Matters of National Environmental Significance	EPA Factor	Existing Environment	Summary of Impacts and Risks
Marine fauna (Environmental factor)	Protect marine fauna so biological diversity and ecological integrity are maintained.	Refer to **Section 4** for a detailed overview of the existing environment as it relates to pygmy blue whales.	• Noise emissions • Vessel strike.
EPBC Act listed threatened species	Not applicable		
EPBC Act listed migratory species	Not applicable		

2.6 Condition Requirements

Condition requirements will be added in a future revision of this plan post State and Commonwealth approval.

2.7 Rationale and approach

2.7.1 Environmental outcome or management objective/s

Environmental management measures to achieve specific performance standards including details of the measurement criteria that will ensure compliance are outlined in **Section 6**.

2.7.2 Survey and study findings

An overview of the available information in relation to pygmy blue whales within the project area is provided in **Section 4**. An overview of further pre-operational studies that will be undertaken prior to the commencement of activities that may impact pygmy blue whales is provided in **Section 7**.

2.7.3 Uncertainties and assumptions

Key uncertainties and assumptions are outlined in **Section 5.3**.

2.7.4 Objective-based EMP

The plan outlines an objective based approach for the management of potential impacts and risks to blue whales from the proposed Browse Project. This approach is seen as appropriate as there are clear and achievable objectives that will result an acceptable environmental outcome.

2.7.5 Rationale for choice of indicators and/or management actions

The rational for the choice of management actions and indicators of impacts is provided in **Section 6**.

3. PURPOSE

3.1 Background

One of the key environmental receptors identified during the assessment of impacts and risks from the proposed Browse Project was the East Indian Ocean (EIO) population of the pygmy blue whale (*Balaenoptera musculus brevicauda*). Pygmy blue whales make annual north and southbound migrations utilising the area identified by the migratory BIA which overlaps with the Browse Development Area and may forage at a number of known and possible foraging, including the possible foraging at Scott Reef which overlaps with the Torosa field and proposed location of the Torosa FPSO and associated subsea gathering system.

A number of planned and unplanned aspects (i.e., elements of the proposed Browse Project that can potentially interact with an environmental receptor) were identified within the draft EIS/ERD as having the potential to result in impacts to pygmy blue whales. A key aspect of the proposed Browse Project is the generation of anthropogenic underwater noise. Underwater noise, at high levels, has the potential to either cause injury to or disrupt potentially biologically significant behaviours.

Within the draft EIS/ERD Section 6.3.8.3 states:

> "*Given that relatively low numbers of transient marine mammals are expected to seasonally occur within the Project Area, only slight behavioural modifications are expected to occur, with no long-term effects at a species population level. These impacts are not considered to be significant, based on the MNES significant impact criteria for listed endangered species and are not inconsistent with the recovery objectives within the Conservation Management Plan for the Blue Whale (2015-2025) (Commonwealth of Australia, 2015)".*

Following publication of the draft EIS/ERD and in finalising the EIS and response to comments on the ERD, further information has been requested by the EPA and DAWE in relation to the interim recovery objectives and targets set out in the CMP, in particular, in relation to demonstrating that the proposed Browse Project is not inconsistent with Action A.2(3) which states that:

> "*anthropogenic noise in biologically important areas will be managed such that any blue whale continues to utilise the area without injury, and is not displaced from a foraging area*".

This plan outlines the potential impacts, proposed mitigations and adaptive management measures that will be applied during the proposed Browse Project to ensure consistency with Action A.2(3) of the CMP and ensure any anthropogenic threats are demonstrably minimised.

3.2 Plan Objectives

The objectives of this plan are to:

- Summarise the significance of the Scott Reef possible foraging area to the pygmy blue whale population, based on existing scientific knowledge (**Section 4**) and summarise the current understanding of underwater noise generating activities (**Section 5**) and the extent of noise propagation (**Section 5.3**).
- Outline the mitigation approach to be taken to minimise the potential environmental impact of underwater noise emissions within the Scott Reef possible foraging area to the pygmy blue whale population (**Section 6, Section 8** and **Section 9**).
- Outline how any underwater anthropogenic noise associated with the proposed Browse Project will be managed such that it will not be inconsistent with the Conservation Management Plan (CMP) for the Blue Whale, specifically the requirements of Action A.2.3.
- Outline the scientific monitoring programs to be undertaken to improve confidence in the environmental impact assessment predictions (**Section 7**), and support the adaptive spatio-temporal management regime to reduce potential environmental impacts of underwater noise within the BIA (**Section 6.2.1**).

- Provide an environmental impact assessment on the residual sources of underwater noise (once mitigations are applied) (**Section 10**).

3.3 Environment Performance Objectives

Implementation of this plan will achieve the relevant aspects of the relevant Environment Performance Objectives (EPO) of the proposed Browse Project, which are as follows:

- 26 – Undertake the Browse Project in a manner that prevents physical injury to marine fauna (cetaceans, marine turtles, whale sharks, dugongs, seabirds and migratory shorebirds).
- 27 – Undertake the Browse Project in a manner that will not disrupt the migration and feeding of the East Indian Ocean pygmy blue whale population.
- 28 – Undertake the Browse Project in a manner that will not displace the East Indian Ocean pygmy blue whale population from the possible foraging area at Scott Reef.

With specific reference to pygmy blue whales, the above EPOs and specific objectives of this plan aim to achieve the following:

- No significant impact to the pygmy blue whale population (EPBC Act threatened and migratory species) as per EPBC Act MNES significant impact criteria for listed endangered species.
- Demonstrate the proposed Browse Project is not inconsistent with Action A.2.3 of the Conservation Management Plan for the Blue whale (2015-2025), Commonwealth of Australia (2015), in accordance with the EPBC Act.

3.4 Structure of this Plan

Key elements of this plan are as follows:

- **Section 4** provides an overview of existing contemporary scientific knowledge regarding pygmy blue whales, including an overview of their observed activity at Scott Reef.
- **Section 5** provides an overview of the sources of anthropogenic noise associated with the proposed Browse Project, including the estimated noise generated from these activities and modelling outcomes or predictions of the impacts of this noise.
- **Section 6** provides the management objectives, approach and spatio-temporal management principles that will be applied to meet the objectives.
- **Section 7** outlines the scientific monitoring and noise verification programs that will be applied, to validate management actions and inform adaptive management.
- **Section 8** provides the key design features and key management actions that will be applied to meet the interim recovery objectives as well as an evaluation against Action A.2(3) of the CMP.
- **Section 9** provides an overview of the Noise Mitigation Plans (NMPs) that will be applied to construction and operational activities.
- **Section 10** provides a summary of the residual underwater noise impacts after the management approach is applied.
- **Section 11** provides a more detailed evaluation supporting the conclusions of the environmental impact assessment for underwater noise and demonstrates that the Proposal is not inconsistent with the Blue Whale Conservation Management Plan.
- **Section 12** outlines the requirement for periodic reviews of the overall management plan and some considerations of the reviews.

3.5 Underwater Noise Impact Assessment Approach

Potential impacts associated with underwater noise in relation to pygmy blue whales as with all marine fauna are complex and the science in this field is rapidly evolving (NOPSEMA, 2020). Sound levels that equate to impact thresholds vary amongst and within faunal groups and are context dependent with reference to the sound source (impulsive or continuous), low-frequency or high-frequency cetacean species, location, bathymetry, nature of the seabed substrate and other physical factors. The adopted thresholds presented in

Table 3-1 and **Table 3-2** are based on the best data available published in peer-reviewed literature and represent conservative internationally accepted and applied impact evaluation thresholds. The key impact thresholds used in this plan are defined as follows:

- Permanent Threshold Shift (PTS) – PTS is considered a reduction in hearing sensitivity from which marine fauna do not recover (permanent hair cell or receptor damage). PTS is considered injurious. Southall *et al*. (2007) define the minimum exposure criterion for injury as the level at which a single exposure is estimated to cause onset of PTS.
- Temporary Threshold Shift (TTS) or Auditory Fatigue – a temporary reduction in the ability of an individual to perceive sound associated with auditory fatigue. TTS is temporary, and full recovery has been demonstrated in a relatively short timeframes (minutes to hours) (Finneran *et al*., 2017). Like PTS, TTS is considered an injurious effect.
- Behavioural disturbance – typically short-term behavioural responses such as avoidance, displacement, or increased surfacing etc. Occurrence and intensity of behavioural disturbance can be highly variable and depends on a range of factors relating to the individual and situation. Behaviour is expected to return to normal following cessation of the anthropogenic noise.

Table 3-1 and **Table 3-2** summarise the impulsive (primarily associated with hammer piling or seismic activities) and non-impulsive (continuous sound source primarily from vessels) sound impact thresholds that may result in PTS, TTS or behavioural disturbance to low-frequency cetaceans (including pygmy blue whales). Within this plan, noise causing behavioural disturbance is used as a proxy for noise that may disrupt foraging behaviours (e.g., it may cause a whale to move on while foraging).

The radii that correspond to SEL24h typically represent an unlikely worst-case scenario for SEL-based exposure because, more realistically, marine mammals would not stay in the same location or at the same distance from a sound source for an extended period. Therefore, a reported radius for SEL24h criteria does not mean that any animal travelling within this radius from the source will be exposed to PTS or TTS, but rather that it could be exposed if it remained within that range for the entire duration the noise source was occurring or a minimum period of 24 hours.

Table 3-1. Acoustic effects of impulsive noise on low-frequency cetaceans: unweighted SPL, SEL$_{24h}$, and PK thresholds

Hearing group	NOAA (2019)	NMFS (2024) & Southall *et al.* (2019)			
	Behaviour	PTS onset thresholds* (received level)		TTS onset thresholds* (received level)	
	SPL (L_p; dB re 1 µPa)	Weighted SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa^2·s)	PK (L_{pk}; dB re 1 µPa)	Weighted SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa^2·s)	PK (L_{pk}; dB re 1 µPa)
Low-frequency cetaceans	160	183	222	168	216

* Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.

L_p denotes sound pressure level period and has a reference value of 1 µPa.

$L_{pk,flat}$ denotes peak sound pressure is flat weighted or unweighted and has a reference value of 1 µPa.

L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa²s.

Table 3-2. Acoustic effects of continuous noise on low-frequency cetaceans: unweighted SPL and SEL$_{24h}$ thresholds

Hearing group	**NOAA (2019)**	**NMFS (2024); Southall *et al.* (2019)**	
	Behaviour	**PTS onset thresholds (received level)**	**TTS onset thresholds (received level)**
	SPL (L_p; dB re 1 µPa)	**Weighted SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa^2·s)**	**Weighted SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa^2·s)**
Low-frequency cetaceans	120	197	177

4. EXISTING KNOWLEDGE: PYGMY BLUE WHALE

4.1 Overview

The blue whale (*Balaenoptera musculus*) is currently listed as Endangered, Migratory and Cetacean under the EPBC Act and Endangered under the WA *Biodiversity Conservation Act 2016* (BC Act, September 2018). There are two subspecies of blue whale that occur within Australian waters and found in the Southern Hemisphere: the Antarctic blue whale, *B. m. intermedia*, and the pygmy blue whale, *B. m. brevicauda*. These two subspecies are differentiated by morphology, distribution, vocalisation and genetics (Commonwealth of Australia, 2015).

The Conservation Management Plan (CMP) for blue whales 2015-2025 (Commonwealth of Australia, 2015) long-term recovery objective is to minimise anthropogenic threats to allow for their conservation status to improve so that they can be removed from the EPBC Act threatened species list. Threats to the blue whale, as identified in the CMP include climate variability and change, noise interference (anthropogenic sources of underwater noise) and vessel disturbance (Commonwealth of Australia, 2015).

Similar to other baleen whale species, blue whales travel long distances twice a year as they generally migrate between breeding grounds at lower latitudes where both mating and calving takes place during the Austral winter, and feeding grounds at higher latitudes during the summer, and the migration routes have overlapping but different spatial distributions (Commonwealth of Australia, 2015). The extent of migrations and the components of the population that undertake such migrations are poorly known. Australian blue whales are represented by three generally recognised and overlapping populations, namely: Antarctic blue whale population; Indo-Australian pygmy blue whale and Tasman-Pacific pygmy blue whale (Commonwealth of Australia, 2015).

The Indo-Australian pygmy blue whales are defined as all those occupying or passing through waters from Indonesia to western and southern Australia. This pygmy blue whale sub-species is now referred to as the East Indian Ocean (EIO) pygmy blue whale population, due to its geographic distribution primarily in the Indian Ocean and south Australian waters (McCauley *et al*. 2018). Pygmy blue whales have known feeding grounds in the Perth Canyon off Western Australia, and the Bonney Upwelling System and adjacent waters off Victoria, South Australia and Tasmania. Individuals migrate between these feeding grounds as well as northwards and southwards along the offshore waters of West Australia to breeding grounds that are likely to include Indonesia (Commonwealth of Australia, 2015). Refer to **Figure 4-1** which shows the pygmy blue whale distribution and foraging areas. These CMP mapped areas[2] correspond to blue whale BIAs based on foraging of varying density and likelihood as mapped in the National Conservation Values Atlas (NCVA), (DAWE 2021). Pygmy blue whales typically inhabit deeper offshore waters historically leading to difficulty in determining migration patterns accurately, however the NCVA includes a defined migration corridor for Western Australian offshore waters (migration BIA), refer to **Figure 4-2**. Migration also seems to be variable, with some individuals appearing as resident to areas of high productivity and others undertaking migrations across long distances (Commonwealth of Australia, 2015).

4.2 Seasonal Migration

Studies over the last ten plus years have contributed valuable insights into the movement and behaviour of pygmy blue whales foraging and migrating through offshore waters of Western Australia. The East Indian Ocean (EIO) pygmy blue whale population is seasonally distributed from Indonesia (a breeding and potential feeding ground) to the southwest of Australia and east across the Great Australian Bight and Bonney Upwelling to beyond the Bass Strait (Blue Planet Marine, 2020). McCauley *et al*. (2018) describes three migratory stages around Australia for the EIO pygmy blue whale population: a ‘southbound migratory stage’ where whales travel southwards from Indonesian waters through offshore Western Australian waters, mostly from October to December

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[2] Annual high use, known and possible foraging areas and areas of distribution as delineated in the CMP for blue whales

but possibly into January of the following year, a protracted ‘southern Australian stage’ (January to June) where animals spread across southern waters of the Indian Ocean and south of Australia, and a ‘northbound migratory stage’ (April to August) where animals meander back to Indonesia again. A satellite tagging study (Double *et al*. (2014) showed tagged whales travelled relatively near to the western Australian coastline (100±1.7 km) throughout March and April until reaching the North West Cape. The whales then travelled northwards and offshore (238.0±13.9 km from the coast) during May towards Indonesia and by June, whales were travelling through the Savu and Timor Sea. A migratory BIA is mapped in the NCVA, refer to **Figure 4-2** and the timing of the northbound and southbound migration periods for Western Australia are presented in Double *et al*. (2014) and Thums *et al*. (2022) satellite tagging studies have shown that EOI pygmy blue whale movement off north-west Western Australia is predominately fast, directed travel (modelled high move persistence) with an average migratory swim speed of 2.8±0.9 km hr^{-1} (Thums *et al*., 2022). Tagged pygmy blue whales have been estimated to swim at an average rate of 21 ±0.7 km per day on the northbound migration en-route to the documented migration terminus within the Banda Sea, Indonesia, where their movements indicate breeding and feeding (Double *et al*. 2014; Möller *et al*. 2020 and Thums *et al*., 2022). Southbound migration for EIO pygmy blue whales is less well documented, however acoustic recordings and limited telemetry data indicate a shorter, faster pulse (as compared to the northbound migration) through the offshore waters of north-west Western Australia in November and December (Thums et al., 2022).

Table 4-1 shows the migration periods of the East Indian Ocean pygmy blue whale population for Western Australia (including the Ningaloo Reef and Scott Reef) based on the available data on timing of northbound and southbound migrations detected via acoustic monitoring and based on telemetry data.

Table 4-1 Seasonality of the East Indian Ocean pygmy blue whale population from the North West Cape to Scott Reef, Western Australia. Sources: (Double *et al*., 2014; McCauley, 2011; McCauley *et al*., 2018)

Pygmy blue whale	J	F	M	A	M	J	J	A	S	O	N	D
Northbound migration				░	▓	▓	░	░				
Southbound migration	░									░	▓	░
Key												
Shoulder period	░											
Peak period	▓											

4.3 Foraging

Blue whales are the largest animal known to exist and are long-lived. They have the highest known prey requirements of any predator, consuming up to two tonnes of krill per day (Commonwealth of Australia, 2015). Their feeding grounds are therefore required to be in areas of high primary productivity that can support sufficient densities of krill, such as oceanographic upwelling, or frontal systems. The feeding aggregation areas of known and high foraging activity (refer to **Figure 4-2**) for the EIO pygmy blue whale population are: (i) Perth Canyon and adjacent waters off Western Australia (Owen *et al*., 2016); (ii) the Great Southern Australian Coastal Upwelling System (GSACUS) (Möller *et al.,* 2020) including the Bonney Upwelling and other smaller upwelling centres off South Australia, Victoria and Tasmania (Gill 2011; McCauley *et al.,* 2018) and (iii) south of the southern Australian mainland and Tasmania along the sub-tropical convergence zone (Garcia-Rojas *et al.,* 2018) including the Bass Strait (Balcazar *et al*., 2015; McCauley *et al*., 2018). Photo-identification studies and genetic testing have confirmed within and between seasonal linkages of these foraging aggregation areas by individual whales (Garcia-Rojas *et al*. 2018; Attard *et al*. 2018). Additional possible foraging BIAs, Ningaloo Reef and Scott Reef within the Northwest Marine Region, are documented in the CMP (**Figure 4-1**). The delineated foraging and possible foraging areas documented in the CMP (Commonwealth of Australia, 2015) extend over vast offshore areas and the presence and numbers of pygmy blue whales within these change in respect to location and timing. This is primarily due to the availability of prey (krill) which is dependent on the inter-annual fluctuations in oceanographic processes supporting productivity in these areas.

Pygmy blue whale foraging behaviour is well documented for the known foraging areas (foraging BIAs) of the Great Southern Australian Coastal Upwelling System (GSACUS) and Perth Canyon. Key characteristics include:

- High numbers of pygmy blue whales recorded with the Perth Canyon area with 35 individual whales recorded on 33 sighting events over 21 days in 2011 (Double *et al*., 2012; Double *et al*., 2014) and 30 pygmy blue whales (13 tagged and 17 recorded by photo identification) over 21 days for the GSACUS (Möller *et al*., 2020).
- High pygmy blue whale occupancy, for example, within the GSACUS most tagged whales remained in the Bonney Upwelling and adjacent areas, utilising this region from at least January to July (Möller *et al*., 2020) and evidence from one individual tagged pygmy blue whale indicated extended periods, i.e., over a month, are spent within the wider Perth Canyon and Naturaliste Plateau region (Double *et al*., 2012; Double *et al*., 2014).
- Pygmy blue whale feeding behaviour includes surface and deep-dive lunge feeding strategies within these known foraging habitats, and modes of feeding change at different times of day (Owen *et al*., 2016; Möller *et al*., 2020). Furthermore, telemetry data reveals relatively short, intensive lunging behaviour when actively feeding within known foraging habitat with high prey availability, as recorded north of Perth Canyon (Owen *et al*., 2016).

Satellite tagging and movement models have also afforded insights into shorter periods of lower travel rates and high turning angles (area-restricted search (ARS) indicating active foraging at Ningaloo (Double *et al*., 2014); north of the North West Cape and south of West Timor (Möller *et al*., 2020), and three main (extensive offshore) areas as indicated by lower move persistence (Thums *et al*., 2022): southern tip of Western Australia to offshore of Geraldton (including Perth Canyon and canyons to the south and north); Carnarvon to the Rowley Shoals (including Cape Range Canyon and Cloates Canyon and in Indonesian waters. Lower move persistence also overlapped with plateau features, including the Naturaliste Plateau (south-west) and the Exmouth Plateau (north-west), Thums *et al*., (2022). Modelled location estimates for the individual whales were primarily overlying slope waters. The foraging BIAs off North West Cape and Scott Reef only encompassed 7% of the most important foraging areas in the north-west of Western Australia. The home ranges and core-use areas modelled by Sahri *et al.,* (2022) indicated similar areas but the focus was on Indonesia and the analysis based only on the original subset of satellite tracks (Double *et al*., 2014). As observed by Möller *et al*. (2020), the traditional 'feast and famine' model for migrating baleen whales (capital breeders) may not apply to pygmy blue whales and the opportunity for supplementary (opportunistic) feeding during migration (north and southbound) may occur when oceanographic conditions support periods of high productivity and prey availability off the continental shelf of Western Australia. The defined EIOPBW migratory route IMMA (as defined by Marine Mammal Protected Area Task Force[3]) describes pygmy blue whales as income breeders adapted to exploit widely dispersed and ephemeral food sources.

4.4 Population Size

There are a number of data sources estimating the population of the EIOPBW. Abundance estimates based on photo-identification mark-recapture from 1999/2000 to 2004/2005 in the Perth Canyon are between 532 and 1,754 individuals (Jenner *et al.* 2008). These estimates match those (662 to 1,559 individuals) determined from acoustic studies in 2004 off the North West Cape of whales migrating

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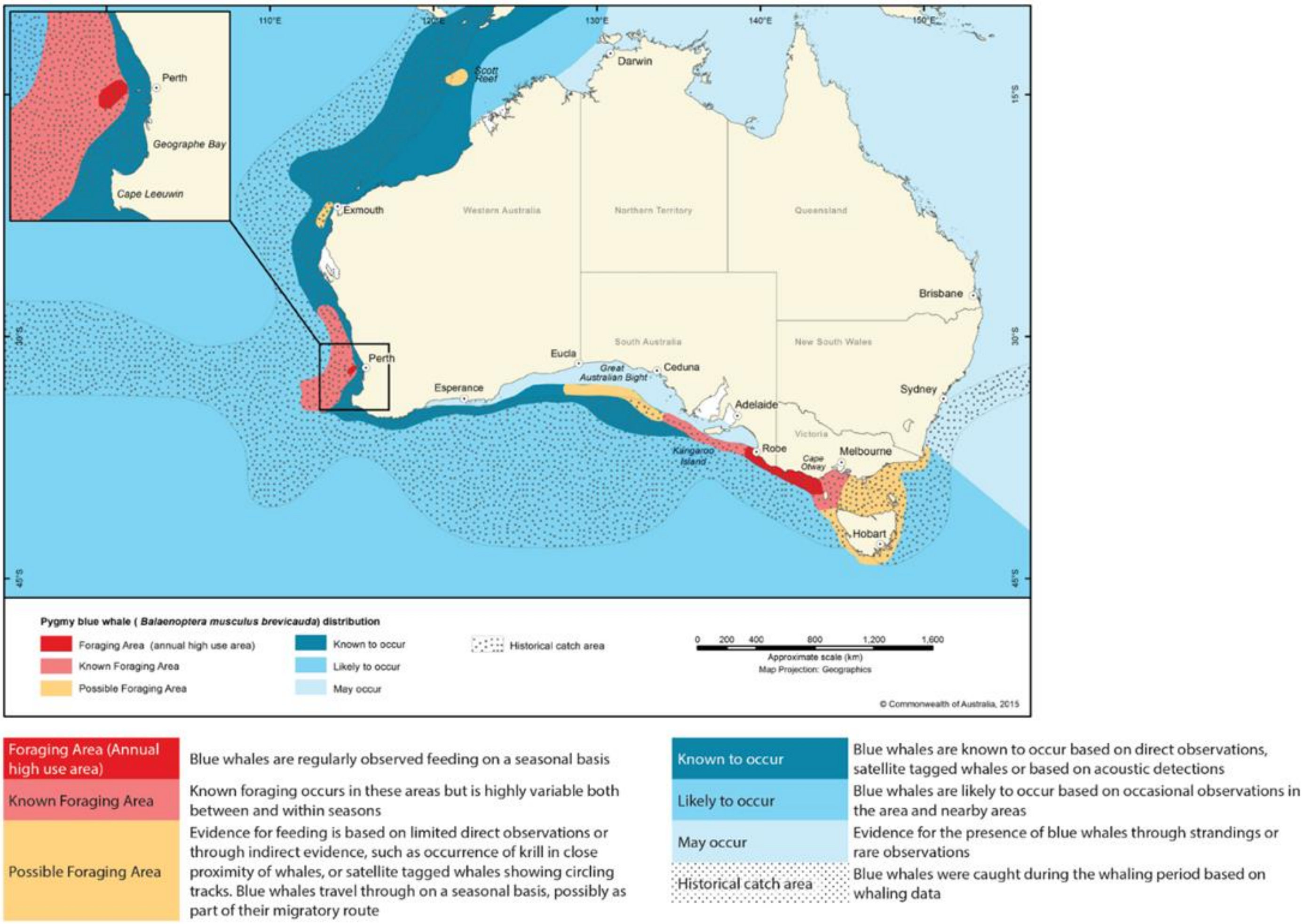
[3] https://www.marinemammalhabitat.org/portfolio-item/eastern-indian-ocean-blue-whale-migratory-route/ (accessed in May, 2022).

southwards (McCauley and Jenner, 2010). Furthermore, a 1992/1993 cruise off southern Western Australia estimated 671 (95% interval 289–1,557) (Kato *et al*., 2007). More recent passive acoustic data estimates a 4.3% growth rate that applies to the proportion of EIO pygmy blue whales using the southeastern Australian coast and may not reflect the full population (whales travelling further west into the Indian Ocean) but does imply an increasing population (McCauley *et al*., 2018). What is not known, is the proportion of the total population these estimates encompass (Commonwealth of Australia, 2015). This is a complex issue as there is the potential for between-year differences in habitat use due to, for example, spatial and temporal differences in primary productivity between years which may bias estimates that are based on only one season of data collection. It is also unknown to what extent and what proportion of the pygmy blue whale population using the Australian feeding aggregations also use feeding habitat outside these areas, such as the relatively more productive Sub-tropical Convergence (Commonwealth of Australia, 2015).



Foraging Area (Annual high use area)	Blue whales are regularly observed feeding on a seasonal basis
Known Foraging Area	Known foraging occurs in these areas but is highly variable both between and within seasons
Possible Foraging Area	Evidence for feeding is based on limited direct observations or through indirect evidence, such as occurrence of krill in close proximity of whales, or satellite tagged whales showing circling tracks. Blue whales travel through on a seasonal basis, possibly as part of their migratory route

Known to occur	Blue whales are known to occur based on direct observations, satellite tagged whales or based on acoustic detections
Likely to occur	Blue whales are likely to occur based on occasional observations in the area and nearby areas
May occur	Evidence for the presence of blue whales through strandings or rare observations
Historical catch area	Blue whales were caught during the whaling period based on whaling data

Figure 4-1 Distribution of and Biologically Important Areas for the pygmy blue whale, *B. m. brevicauda*, around Australia (Commonwealth of Australia, 2015)

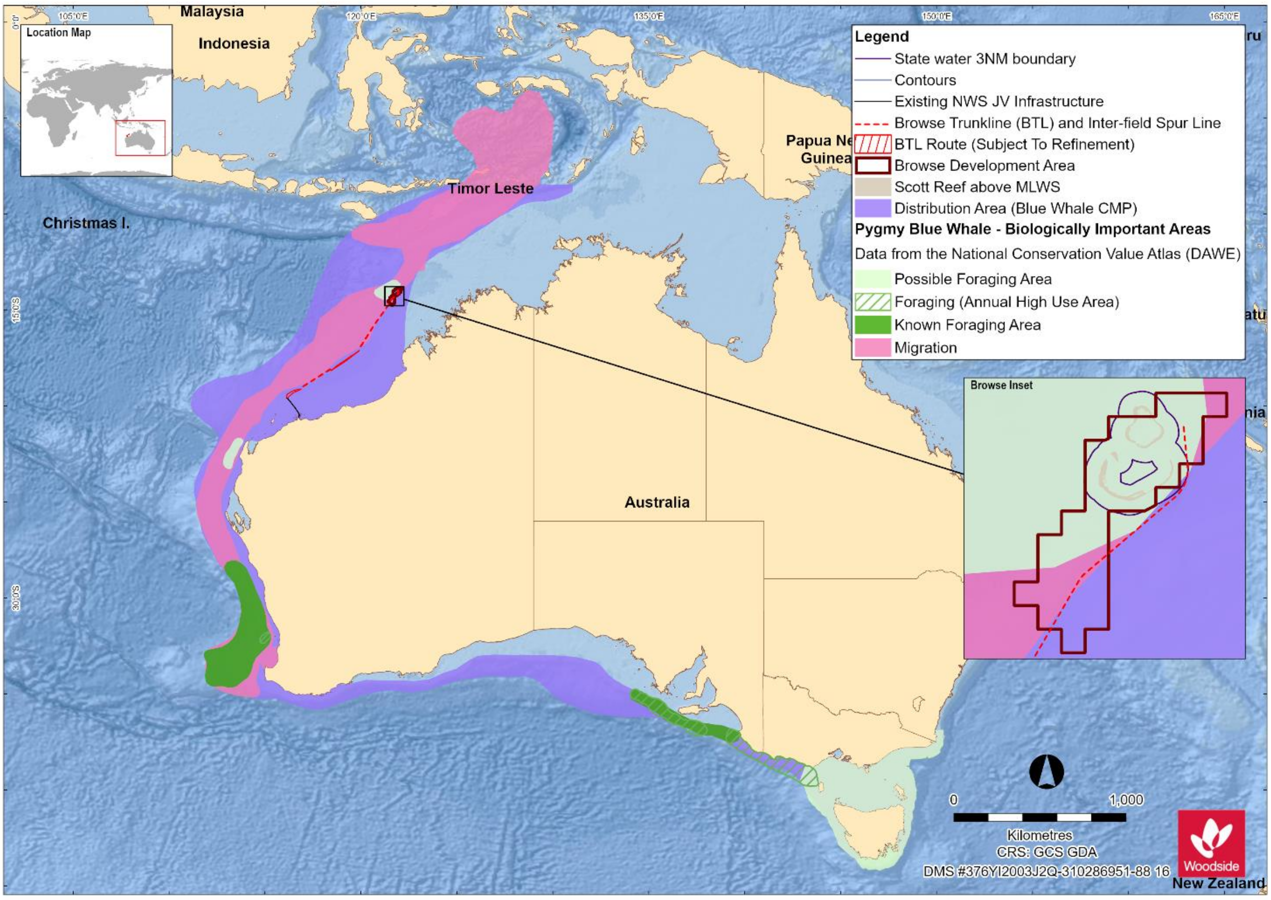


Figure 4-2 Distribution area and foraging/migratory BIAs for pygmy blue whales. Source: National Conservation Values Atlas (NCVA).

4.5 Pygmy Blue Whale Possible Foraging Area at Scott Reef

The possible foraging area at Scott Reef encompasses North and South Scott Reef and the deep-water channel between the reefs, as well as an extensive area of oceanic waters extending west of Scott Reef. The total area of the possible foraging area as defined in the Blue Whale CMP and NCVA at Scott Reef is 12,197.5 km^2. In relation to the proposed Browse Project, all of the drill centres in the Torosa field as well as the Torosa FPSO location are within the possible foraging area and the Torosa, Calliance and Brecknock development areas overlap the migratory BIA for pygmy blue whales (**Figure 4-3**).

Presence and Timing of pygmy blue whale*s at Scott Reef*

Detection of pygmy blue whales in and around the Scott Reef area during the northbound and southbound migration periods has been made over multiple years using both passive acoustic recordings and visual sightings.

The presence of EIO pygmy blue whales was consistently recorded using passive acoustics for the north and southbound migration periods in the Scott Reef Area, including the Scott Reef channel, separating North and South Scott Reef (McCauley 2011). A program of noise logger deployment (funded by the Browse JV) was conducted from 2006 to 2011 and the acoustic detection data acquired used to describe of the presence of whales, fish and anthropogenic noise within and surrounding Scott Reef. McCauley (2011) reported pygmy blue whales migrating through the Scott Reef region twice per year, northbound over mid-April to early August, with peak passage May and June (2007, 2008 and 2009) and southbound in October to December and potentially into January the following year, with peak passage in late October through November (listening period: 2006, 2007 and 2008), **Figure 4-4**. There was evidence for preferred routes used by pygmy blue whales around Scott Reef, primarily to the west of the reef system, based on northbound migration detection.

McCauley (2011) summarised the acoustic detection of pygmy blue whales from the Scott Reef dataset as follows:

- An extended northbound migration of pygmy blue whales past Scott Reef from mid-April to early August detected in 2007, 2008 and 2009. First and last detections 1st April and 14th August (for all PAM datasets).
- A southbound migration pulse of pygmy blue whales from October to mid-January (in 2006 and 2008 but not in 2007). First and last detections 6th October and 17th January (for all PAM datasets).
- No pygmy blue whales were detected inside the Scott Reef southern lagoon.
- Pygmy blue whales were detected travelling through the Scott Reef channel (separating North and South Scott Reef) on at least nine occasions between September 2008 and June 2009. Further analysis of detections for this same period showed 25 individuals were detected in the channel and of those, 14 were estimated to be whales in the middle of the channel.
- Acoustic detection recorded single calling pygmy blue whales 78% of the time but groups of two animals calling were also recorded (18% of the time).
- Inter-annual variability in whale detections were recorded reflecting variation in migratory routes and timing. An increasing number of whales over the 2007 to 2009 northbound migratory seasons and little detection of the southbound migratory pulse in 2007.
- Only between 6-40% of pygmy blue whales passing the North West Cape (Exmouth) pass by Scott Reef. The lower numbers of pygmy blue whales recorded off Scott Reef as compared to the North West Cape suggest only a fraction of the whales which pass up and down the Western Australian waters utilise the shelf break further north and that other migrating pygmy blue whale may move into deeper areas of the Indian Ocean further to the west.

Eight pygmy blue whales were sighted in the Browse basin and six of these whales were in the Scott Reef channel or in its proximity based on the results of dedicated surveys over a period from June 2008 to October 2010, representing over 700 hours of survey effort. Marine megafauna vessel and aerial-based surveys were conducted at Scott Reef and the wider Browse basin by dedicated marine scientists and trained observers (Jenner and Jenner, 2011; RPS Environment and Planning, 2010 and 2012; Sutton *et al*., 2019). The actual pygmy blue whale sightings were as follows:

Visual sightings from dedicated vessel and aerial surveys in 2008:

- A total of five pygmy blue whales sighted at Scott Reef in October 2008 and all on the same day:
  - On 30th October 2008, two blue whales were observed swimming through the Scott Reef channel from the eastern to western entrance. Three additional pygmy blue whales were then observed at the western entrance of the Scott Reef Channel (Sutton *et al*. 2019), refer to **Figure 4-5**.
- Jenner and Jenner (2011) observed one pygmy blue whale on the first day of aerial surveys over Scott Reef on 3rd August 2008; the individual was observed swimming northward <1 km from the western entrance of the channel between North and South Scott Reef.

Additional information:

- No pygmy blue whales were recorded during fine-scale transects carried out in the Scott Reef channel in early and late November 2008.
- Two additional sightings account for the total of seven pygmy blue whales as documented by Sutton *et al* (2019): one pygmy blue whale was observed approximately 200 km east of Scott

Reef in winter (June 2008) and one individual observed approximately 50 km northwest of Scott Reef in spring (November 2008).

In addition to the independent scientific surveys, dedicated marine fauna observer sightings as part of the environmental compliance for seven marine seismic surveys over the period 2005 to 2012 recorded a total of two pygmy blue whale sightings in proximity to Scott Reef (**Table 4-2**). The marine seismic surveys generally operated over the period August to November and employed dedicated and qualified marine fauna observers on watch during daylight hours, representing an estimated >4,500 hours of observation effort (based on 12 hour watch periods per day) during moderate to very good sea state.

Table 4-2 Woodside Marine Seismic Surveys at Scott Reef and surrounds (2005-2012)

Marine Seismic Surveys	Duration
Snarf 3D MSS (2005)	40 days
Torosa 3D MSS (2005)	26 days
Maxima 3D MSS (2007)	57 days
Gigas OBC MSS (2008)	30 days
Rosewall/Calliance 3D MSS (2007/2008)	179 days
Tridacna 3D OBC MSS (2011)	92 days
Rosebud 3D MSS (2012)*	19 days
*Pygmy blue whale sighting x1 (northeast of North Scott Reef in October 2012) and x1 sighting record from 2005 though report unconfirmed)	

Sightings data for a marine seismic survey south of Timor Leste provided evidence that the detection of high pygmy blue whale activity can be recorded by dedicated marine fauna observers as part of the environmental compliance for such surveys. Sightings data from a seismic survey conducted by ENI over a 22 day period in September 2007 off the south of Timor Leste, recorded 13 pods of blue whales (18 individuals) and 8 pods of unidentified large whales (which they concluded were also most likely to be blue whales), Eni Timor Leste (2007).

The far higher number of sightings during this short period south of Timor Leste in comparison to the sightings and acoustic detection at or in proximity to Scott Reef over multiple years indicates that although a number of pygmy blue whales do pass through the Scott Reef area seasonally, its relative importance to the EIO population is likely to be relatively low compared to other areas surveyed along the northbound migratory route. Thums *et al.* (2022) concluded that the importance of Scott Reef is not clear based on the collated analysis of all satellite tracked pygmy blue whale data. However, the regional wide collated Northwest Marine Region PAM data over a ten-year period, showed highest effort but lowest call detection for the Scott Reef area in comparison to the southern North West Shelf offshore area (Thums *et al.*, 2022).

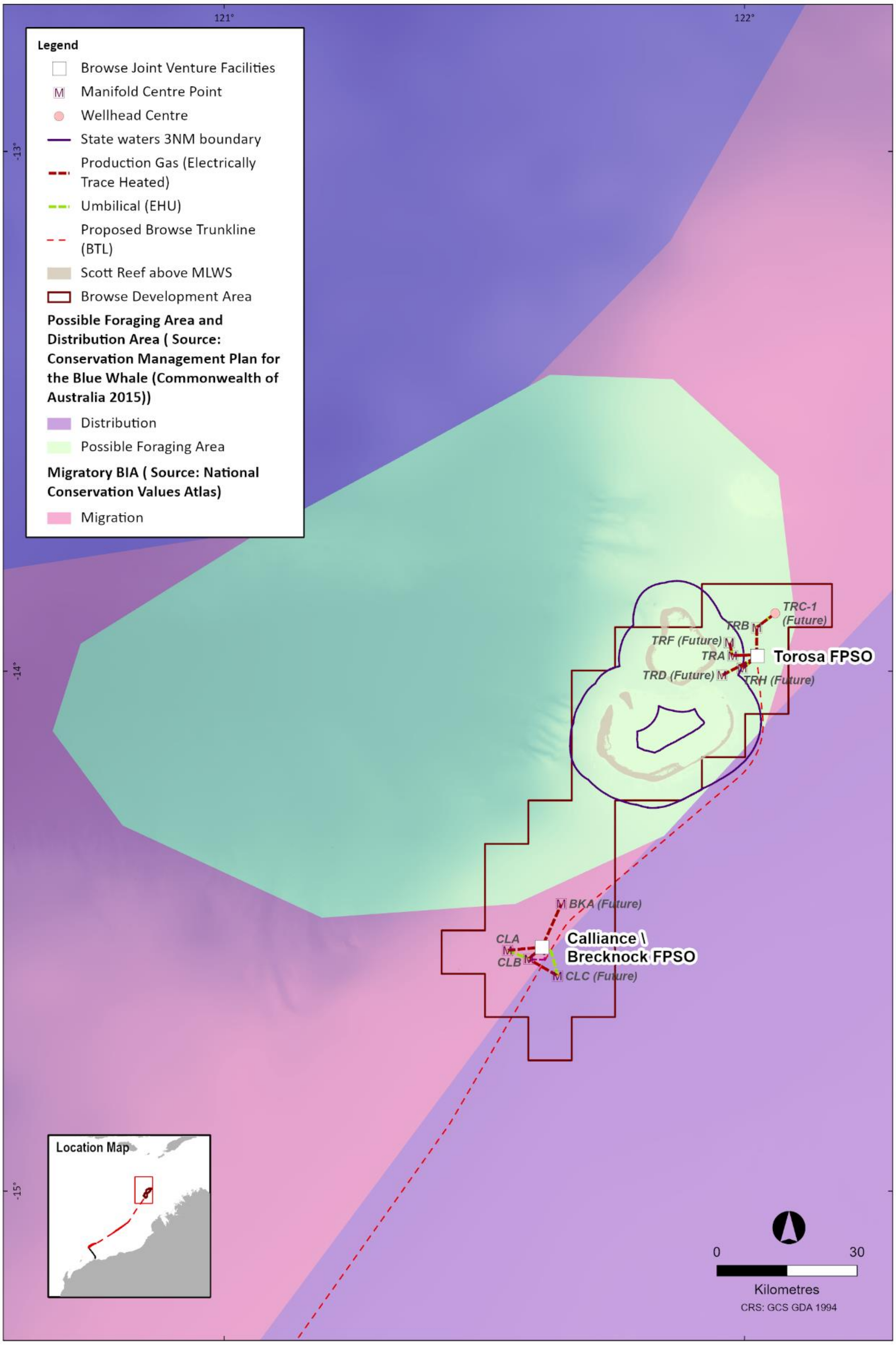


Figure 4-3 The possible foraging area (foraging BIA) for pygmy blue whales at Scott Reef, and migration and distribution BIAs, and the proposed Browse Development Area (source: CMP (Commonwealth of Australia, 2015) and NCVA (DAWE, 2021)

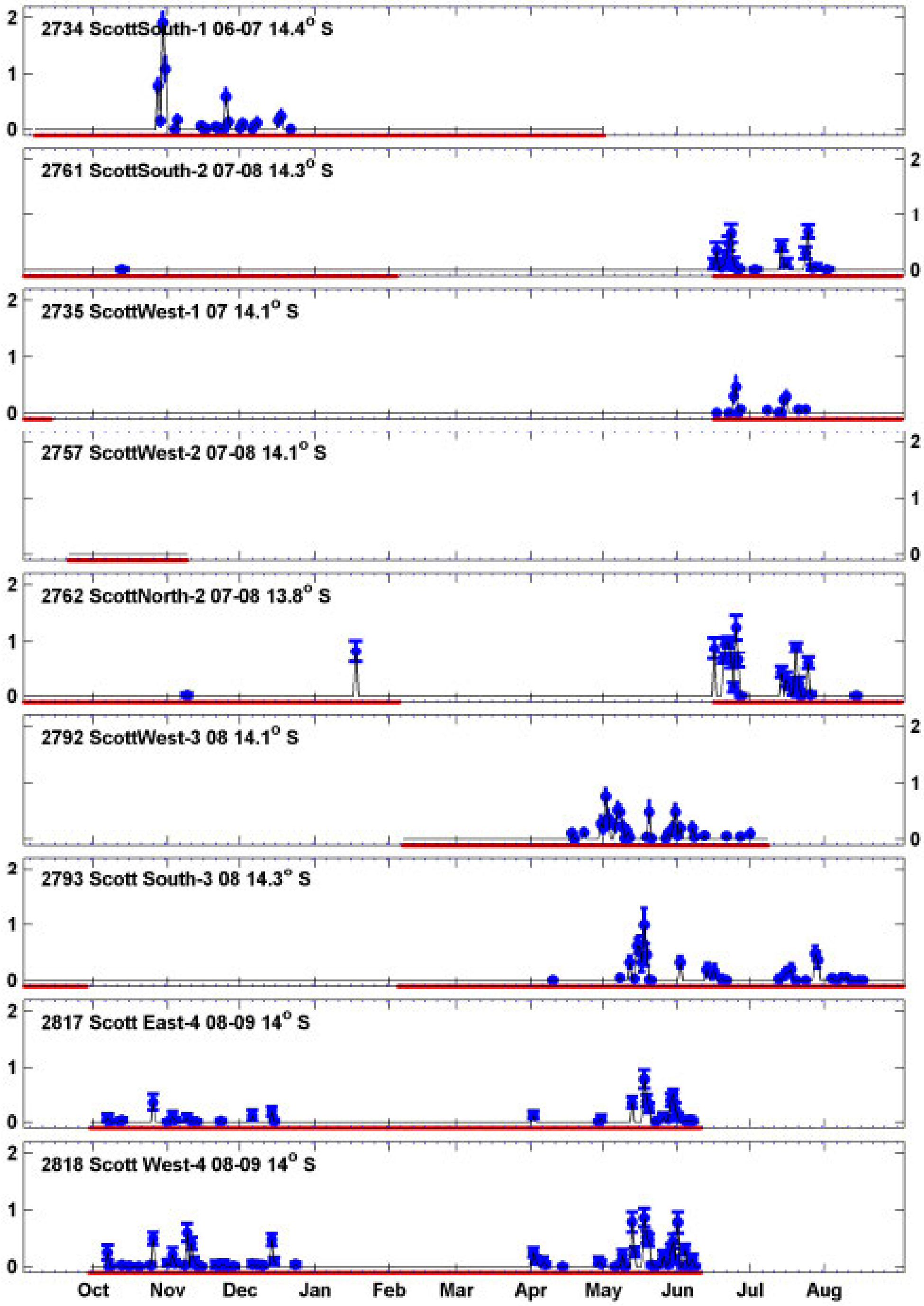


Figure 4-4 Numbers of individual pygmy blue whales calling per 200 seconds averaged in 24 hour periods 12:00 – 12:00 hours, for all Scott Reef logger data available, per calendar year. The full sampling period for each dataset is shown by the bottom red line. Minor tick marks are five day intervals. (McCauley, 2011)

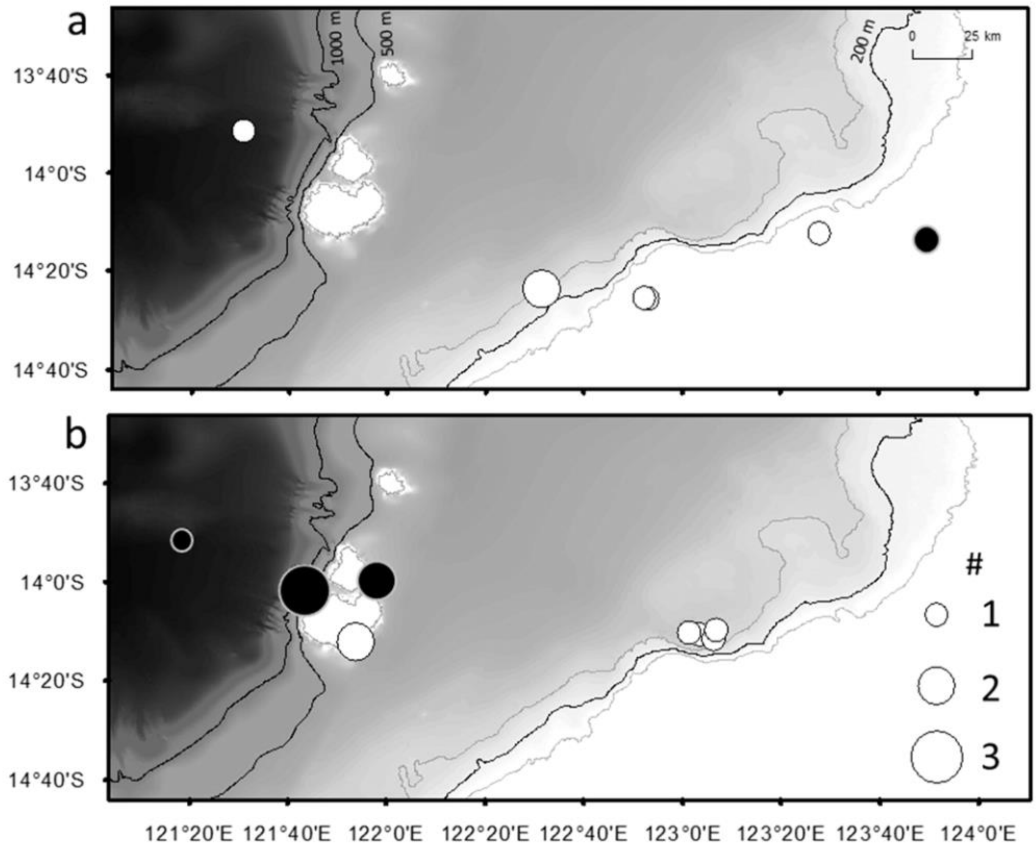


Figure 4-5 Locations of encounters and the number of individuals per encounter for *mysticetes* across the Browse Basin in a) winter b) spring 2008. Black circles indicate encounters of pygmy blue whales (Sutton *et al*. 2019).

4.5.1 Likelihood of Foraging Behaviour

The observed opportunistic feeding behaviour of migrating pygmy blue whales outside known foraging habitat (BIAs) combined with the documented annual spring productivity for the shelf edge of the Browse region and within the Scott Reef area, particularly the Scott Reef channel (Sutton *et al*. 2019) contributed to supporting the delineation of the possible foraging area at Scott Reef.

Scott Reef and the adjacent waters (extending to the west) are defined as a possible foraging BIA. A possible foraging area /BIA as defined in the Blue Whale CMP: "evidence for feeding is based on limited direct observations or through indirect evidence, such as occurrence of krill in close proximity of whales, or satellite tagged whales showing circling tracks". Unlike at the known foraging BIAs such as the Perth Canyon and the Bonney Upwelling, where foraging occurs over extended periods of time on an annual basis, pygmy blue whales at Scott Reef have not been directly observed foraging (no evidence of surface or deep dive lunge feeding). Pygmy blue whales have, however been sighted at Scott Reef (at the entrance and within the channel between North and South Scott Reef) during a spring period of elevated plankton biomass recorded for the wider shelf edge of the Browse region and live krill specimens collected from the central southern edge of the channel (Sutton *et al*. 2019). Evidence reportedly indicating possible foraging habitat and the opportunity for supplementary feeding by southbound migrating pygmy blue whales (Sutton *et al.,* 2019).

Evidence for predictable foraging habitat for pygmy blue whales within the possible foraging area at Scott Reef is unclear. The Scott Reef channel acts as both a conduit for focussing internal waves (solitons) and also as a generator of these waves, due to stratification of the water column and constriction due to being situated between North and South Scott Reef. The Scott Reef channel is a very high energy environment and is expected to be a dynamic environment where strong currents and tidal flow sweep through the inter-reef channel. Sampling of the deep water in the channel suggested that zooplankton were more concentrated in the mixed water layer (less than 100 m depth) than other locations in the area. The zooplankton samples were dominated by large copepods though six species of krill (euphausiids) were also recorded. Brinkman *et al*. (2010), however concluded it was unclear if krill species were at an abundance or density that would support pygmy blue whale feeding. The effects of emergent reefs and submarine features on localised primary productivity were noted in the Marine bioregional plan for the North-west Marine Region (Commonwealth of Australia 2012). A study by CSIRO (Schroeder *et al.,* 2009) indicated that the deep oligotrophic waters of the Indonesian Throughflow Current (ITF) are a barrier to convective upward mixing of nutrients in the region and therefore upwellings within this zone are unlikely to reach the surface, being limited to sub-surface waters above the thermocline. Instances of surface upwellings are likely to be the result of episodic oceanographic events as opposed to predictable seasonal occurrences (Schroeder *et al.,* 2009). Hence, surface chlorophyll values do not necessarily provide an accurate picture of the seasonal primary production that occurs in this region (Schroeder *et al.,* 2009). Nevertheless, the study did acknowledge that the structure of Scott Reef and its interaction with a variety of oceanographic processes may affect local productivity around the reef, with highly localised upwelling and downwelling processes influencing phytoplankton abundance (Schroeder *et al.,* 2009). Brinkman *et al*. (2010), showed horizontal and vertical mixing processes were at their highest within the Scott Reef channel due to the interaction of internal waves and semi-diurnal internal tide with the topography, and the enhanced mixing resulted in a broad chlorophyll maximum spanning a large proportion of the mixing layer below surface waters (25-125 m depth).

The delineated possible foraging area is a very large area with a conservative buffer and it is likely that in reality there are foraging pockets within this BIA associated with habitat suitability and oceanographic processes that periodically support prey availability. **Figure 4-6**, presents the bathymetry for the BIA area of Scott Reef showing the upper slope and canyon features to the west of Scott Reef, the Scott Reef system (including the inter-reef channel) and the deepwater, homogeneous (featureless) habitat of the eastern extent of the BIA, the proposed location of the Torosa field (proposed Browse Project). Modelling of the movement and behaviour of pygmy blue whales based on telemetry data for northbound migration tracks (Thums *et al.*, 2022) showed 89±9.3% of modelled location estimates were overlying slope waters indicating extensive use of the slope habitat by migrating pygmy blue whales off Western Australia. Most important foraging areas as modelled by Thums *et al.* (2022) included the shelf edge from Ningaloo to Rowley Shoals. Adopting the slope habitat as a predictor of habitat suitability would indicate the outer slope with canyon features on the western side of Scott Reef probably has a higher likelihood of seasonal prey availability and foraging habitat for pygmy blue whales. The surrounding open water environment of the eastern extent of the BIA (east of Scott Reef) represents a deep water, homogeneous sediment seabed habitat with a lack of geomorphological seabed features. If krill swarms are present within the water column of this open water environment, they are likely to be ephemeral and patchy in nature, and any pygmy blue whale foraging occurrence is expected to be of a low likelihood and opportunistic in nature.

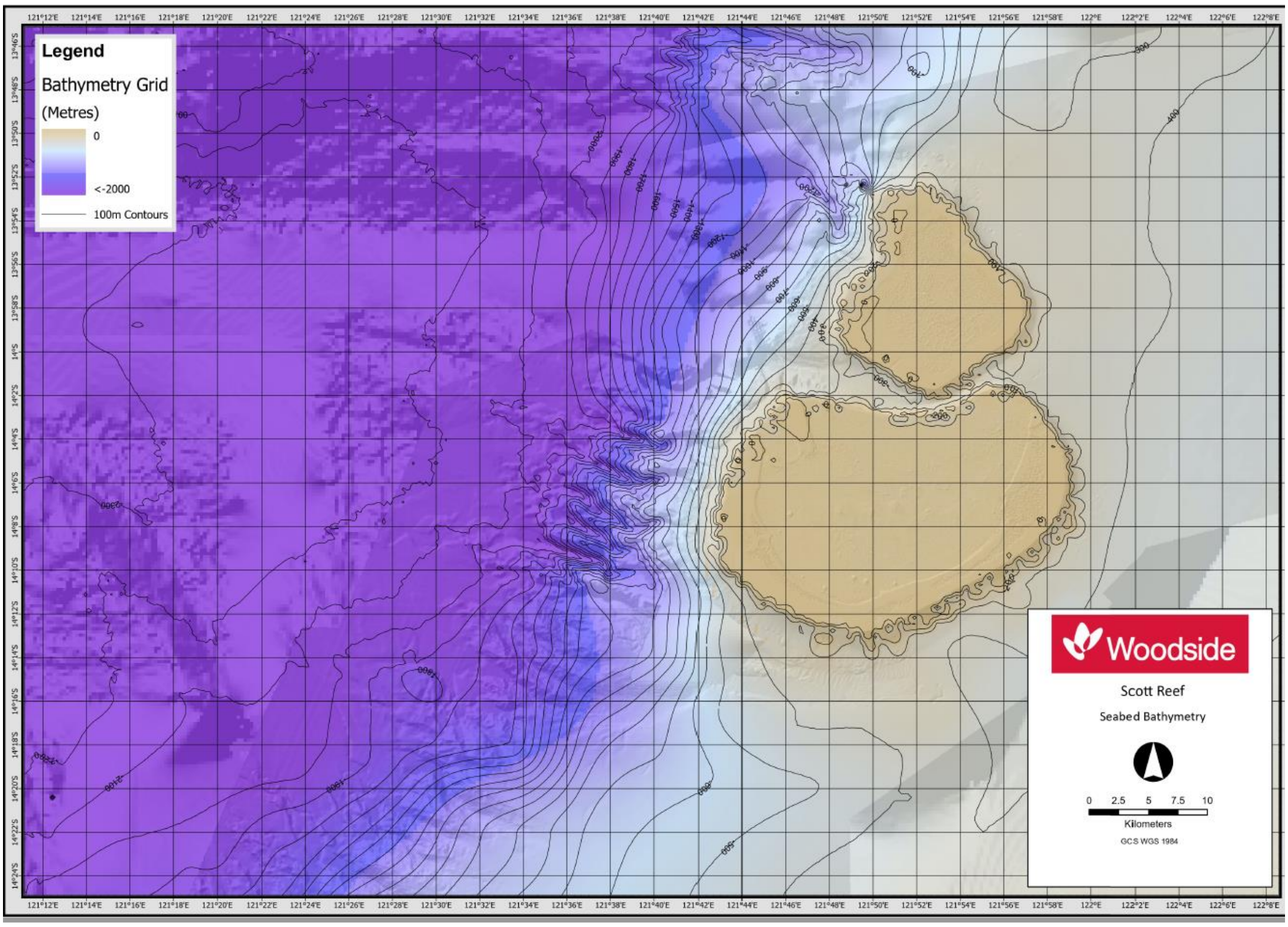


Figure 4-6 Bathymetry and geomorphological Scott Reef structure across the west-east extent of the Scott Reef possible foraging area.

4.5.2 Scott Reef Possible Foraging Area Conclusions

North and southbound pygmy blue whales are known to migrate on an annual basis through the Scott Reef possible foraging area on their way to and from breeding and feeding grounds within the Banda Sea, Indonesia. The migratory seasons are defined by shoulder and peak periods and exact timings can vary inter-annually.

Blue whales travel through the Scott Reef possible foraging area on a seasonal basis as part of their migratory route to and from the Banda Sea. However, existing knowledge of pygmy blue whale relative abundance, movement and behaviour (ENI Timor Leste 2007; McCauley 2011, Double *et al*. 2014; Möller *et al*. 2020 and Thums *et al*., 2022) suggests that visitation rates and residence times are likely to be markedly lower than other known and possible foraging areas to the southwest such as Ningaloo and the Perth Canyon.

Evidence collected to date from a variety of techniques including sampling of zooplankton, pygmy blue whale vocalisation data from noise loggers, survey observations and satellite tag tracking suggests that Scott Reef is likely to be of less importance for the East Indian Ocean (EIO) pygmy blue whale population than other defined foraging areas. However, the relative importance of the entire Scott Reef possible foraging area or areas within it as foraging habitat for migrating pygmy blue whales remains unclear and as such the possible foraging area will be managed as a known foraging area for the purposes of the proposed Browse Project.

In known foraging BIAs such as the Perth Canyon and GSACUS pygmy blue whales can be observed in predictable annual higher abundance, exhibiting foraging behaviours and have extended residence times albeit over extensive areas of coastal or offshore waters. These observations, behaviours and residence times are not replicated at Scott Reef, despite dedicated, multi-year studies over an extended period, using multiple survey and sampling techniques. This leads to the conclusion that if foraging by pygmy blue whales does occur within the wider Scott Reef possible foraging area it is likely that this is opportunistic foraging only, commensurate with the classification of the pygmy blue whale as an income breeder. Based on Sutton *et al.* (2019), who inferred that a predictable spring period of higher productivity occurs within the Scott Reef channel support foraging by pygmy blue whales. A higher relative importance of the Scott Reef channel as a potential foraging habitat within the Scott Reef possible foraging area, particularly, for southbound migrating pygmy blue whales has been adopted within this plan underpinning the adaptive management regime for underwater noise emissions and potential impacts to pygmy blue whales.

5. SOURCE OF ASPECT: ACTIVITIES GENERATING UNDERWATER NOISE

Underwater noise emissions will occur during all stages of the proposed Browse Project. Activities potentially generating underwater noise emissions have been separated into four categories, which aligns to the way in which management measures are applied within this plan. The four key categories and specific noise generating sources in each category are as follows:

- **Drilling and completions**
  - Mobile offshore drilling unit (MODU) topsides drilling & completion activity and associated facility noise
  - MODU (dynamic positioning system noise)
  - Operation of offshore support vessels (OSVs) to support MODU operations (e.g. goods transfer)
- **Subsea and FPSO Construction and Installation**
  - Construction vessels, including
    1. Offshore Installation Vessels, including flexible flowline installation vessels, used to install flowlines and other subsea infrastructure (e.g. umbilicals, x-mas trees)
    2. Rigid pipelay vessels, used to install the Browse Trunkline and flowlines.
    3. Anchor holding tugs, used to hold the FPSO in position while permanent anchors are installed
- **FPSO Operations**
  - FPSO topsides processing and associated facility noise
  - FPSO thrusters, used for heading control
  - Operation of OSVs to support the FPSO operations (e.g. transferring goods and equipment to the FPSO)
  - Condensate offtake activities, involving a condensate tanker and OSV
- **Well head Operations (choke valves)**
- **Impulsive Noise Source Activities**
  - Impact (hammer) piling
  - Subsurface evaluation using well bore seismic imaging techniques (e.g. vertical seismic profiling)

Sounds source level estimates for various activities/scenarios and these are provided in **Table 5-1**.

Table 5-1. Sound source level estimates from key project activities

Sound Source	**Sound Level Estimate (dB re 1 µPa·m)**	**Comments**
SURF and FPSO Installation		
Offshore installation or flexible reel-lay vessel (e.g. flowline installation) [1]	181	Short term (1 week per flowline + 1 month for other infrastructure).
FPSO Mooring and subsea Hookup (approx 4 vessels) [2]	5 vessels x 184 each	Short term (1 month for FPSO, 2 months for subsea hookup).
Rigid Pipelay Vessel, considering attendant support vessels [3]	191	Short term (2 weeks), estimate includes a single B-type vessel alongside.
Drilling and Completions		
MODU (moored, no drilling) [13]	163	
MODU (moored, drilling) [4]	171	
MODU (moored, with OSV alongside for resupply) [4], [5]	182	Short term (12 hours).
MODU (Using Dynamic Positioning (DP)) [6]	183	
MODU (Using DP, with OSV alongside for resupply) [5], [6]	185	
FPSO Operations		
FPSO (No thrusters) [7]	174	
FPSO (Offtake) [5]	186	
FPSO (OSV Resupply, no thrusters) [5], [7]	182	
FPSO (50% thrust) [8]	183	Does not consider available design mitigations.
FPSO (100% thrust) [8]	189	Does not consider available design mitigations.
FPSO (50% thrust + OSV resupply) [5], [8]	185	
FPSO (50% thrust with design mitigations incorporated) [9]	178	Design mitigations for the FPSO thrusters are as described in **Section 8.3**.
FPSO (50% thrust + OSV resupply, with design mitigations incorporated) [5], [9]	183	Design mitigations for the FPSO thrusters are as described in **Section 8.3**.
Offshore support vessel (During Offtake) [5]	186	
Offshore support vessel (During Resupply) [5]	181	
Well Head Operations		
Wellhead Choke Valves (Excluding design mitigations) [10]	161.5	

Sound Source	Sound Level Estimate (dB re 1 µPa·m)	Comments
Wellhead Choke Valves at each well centre (with design mitigations incorporated)	147.3	Estimated based on potential design mitigations described in **Section 8.3**.
Impulsive Noise Sources		
Vertical Seismic Profiling	Refer Table 5-2	
Driven Piling	185–199 re 1 µPa2·s at 10 m (IHC S-600 and IHC S-1200 hammers, respectively)	Further mitigations can be applied as described in **Section 8.**

[1] Based on *Deep Orient*. Quijano and McPherson 2021.

[2] Based on *Katun*. Hannay et al 2004.

[3] Based on *Castarone and B-Type*. Brodin et al 2022a.

[4] Based on *Transocean Polar Pioneer*. Austin et al 2018.

[5] Based on *Fugro Etive*. Brodin et al 2022a.

[6] Based on *DPS-1*. Brodin et al 2022a.

[7] Based on *Nganhurra* and *Ngujima Yin*. Erbe et al 2013.

[8] Modelled based on example thruster without further design mitigations. Brodin et al 2022b.

[9] Estimated based on example thruster with design mitigations. Brodin et al 2022b.

[10] Based on supplier estimates.

[11] Estimated by McPherson et al 2019.

[12] Estimated by McPherson et al 2019.

[13] Based on Austin et al 2023

5.1 Continuous Noise Sources

5.1.1 Drilling and Completions

The proposed Browse Project is expected to use a semi-submersible MODU for drilling and completions activities. Prior to the initial construction and installation of subsea and FPSO facilities at the Torosa field, a MODU is expected to be present, drilling for up to two years. A MODU will also be required for drilling and completions activities to support subsea tie-back phases that will occur after the initial Torosa FPSO RFSU period – these are described in **Section 2.4**.

5.1.1.1 MODU Station Keeping

The noise emissions from a MODU primarily depend upon whether the MODU is moored or using a dynamic positioning (DP) system to hold station (i.e., a constant position to allow for safe operation). The broadband drilling source levels (i.e., noise generated when the facility is moored and does not use DP to hold station) reported in Austin *et al*. (2018) was 170.1 dB re 1 µPa·m for a semi-submersible MODU.

If the propulsion system of a vessel is under heavy load (acceleration, DP) the sound produced by the cavitation process on the propellers will dominate other sources of vessel sound (drilling, machinery, hull vibration, etc.). However, the source level depends upon the thruster design, the total number of thrusters and the load placed on each, and as such will change depending upon environmental conditions.

For the proposed Browse Project, a preliminary Dynamic Positioning Analysis has been completed using metocean data to determine the amount of thrust required for a DP MODU to hold position at

Torosa drill centres. The DP Analysis utilized metocean data specific to the TRD location and the hull dimensions of a DP MODU that is representative of a typical DP MODU that may be used for the proposed Browse Project. The Dynamic Positioning Analysis concluded that a typical DP MODU designed with eight 3.8 MW thrusters would only require 40% of four thrusters to safely maintain position in a 1-year return period non-cyclonic condition, which would result in an underwater sound source level of approximately 183 dB re 1 µPa·m.

5.1.1.2 MODU Drilling

For a moored MODU, the predominant underwater noise source is generated by the action of the drill bit at or below seabed when drilling out the wellbore. Underwater noise from a moored MODU drilling at various depths was reported in Austin *et al.* (2023), who found that underwater noise generation reduced as the wellbore got deeper (i.e. as the drill bit moved further away from the seabed).

While Austin et al. (2023) did not provide an estimate of a moored MODU without drilling, the underwater noise source estimate of a moored MODU when drilling the deepest section was approximately 162.7 dB re 1 µPa·m.

For a dynamically positioned MODU, underwater noise generation is dominated by the thrusters used for station keeping.

5.1.1.3 Project Support Vessels (PSVs)

During a resupply activity where a PSV is holding a steady position alongside another vessel (e.g., MODU, FPSO or construction vessel) to which goods are being transferred, a PSV is required to utilise its DP system to maintain a steady position. During resupply, a PSV is estimated to have an individual sound source level of 181.3 dB re 1 µPa·m, based on analysis by DNV using the *Fugro Etive* as an analogue vessel.

When a PSV comes alongside a moored MODU (e.g. to transfer goods or as required for safety reasons in certain circumstances (e.g. helicopter landing)), the underwater noise will be dominated by the PSV using its DP system to maintain position.

This activity will be governed by a Noise Mitigation Plan (NMP) (refer **Section 5.4**) and noise could be abated, or the activity not commenced, if a foraging pygmy blue whale was present.

5.1.2 SURF and FPSO Construction and Installation

The initial (pre-RFSU) construction and installation of subsea and FPSO facilities at the Torosa field location extends for approximately two years (see **Section 2.4**). Various construction vessels will be used for the construction phase of the proposed Browse Project. The operation of motorised vessels involves numerous mechanical processes which create underwater sound as a by-product; these range from sound of the propeller, cavitation caused at the propeller edges, machinery or simply the flow noise of the vessel moving through the water. Sound emitted from vessel differs strongly depending mainly on size, speed, load, type and state of propulsion system, meteorological and oceanographic factors such as sea surface conditions and currents (MacGillivray *et al*. 2018).

Offshore installation vessels (for installation of SURF infrastructure)

Underwater noise from a representative construction vessel (Deep Orient) was measured during DP trials to have sound pressure source levels in the range of 180-182 dB re 1 µPa·m (JASCO 2021).

Rigid pipelay (for installation of the Interfield line)

A rigid pipelay vessel will be required to lay the inter-field spur line between Calliance and Torosa. There is a limited pool of vessels that can lay the inter-field spur line given its size and the water depth. A DNV 2021 underwater noise analysis of thruster usage of the *Castorone* is considered representative of the underwater noise generated by the rigid (interfiled line) pipelay vessel. This analysis estimated an underwater source noise of 191 dB re 1 µPa·m for the dynamic positioning system of the *Castorone* (with a *B-type* vessel alongside). Other vessels when required to work in the vicinity of the rigid pipelay vessel may result in increased sound levels, however these represent short term increases on an already short term activity (two weeks).

Anchor handling (for holding the FPSO in position while permanent anchors are connected)

For FPSO hookup, it is anticipated that approximately four anchor handling vessels would be required. A representative anchor handler (*Katun*) was measured during anchor pull to have sound pressure levels of 184.4 dB re 1 µPa·m (Hannay *et al* 2004).

5.1.3 FPSO Operations

5.1.3.1 Torosa FPSO (Standard operations without using thrusters for heading control)

In the majority of weather conditions, no mechanical propulsion will be required to hold the Torosa FPSO in the correct position for safe operation, so any noise from the facility will be from the propagation of vibration from mechanical equipment (e.g. compressors, pumps) through the vessel hull and into the water column. The FPSO will weathervane (freely move) on the turret mooring during this time.

The vessel type and specifications of the Torosa FPSO are similar to the Woodside FPSO facilities *Ngujima Yin* and *Nganhurra*, from which JASCO gathered measurements in 2010 (Erbe et al. 2013). The measured spectra for these two vessels were averaged and used as a surrogate for the FPSO facility. Because the *Ngujima Yin* and *Nganhurra* were moored, they were not offloading, and the weather was calm, they were not using any form of position or propulsion system when they were measured. The only noise being generated from these vessels was from topsides mechanical noise and facility vibration, representative of what would be typically expected to occur from the Torosa FPSO. These averaged source levels were used in this report to model FPSO operations without using thrusters. The draft EIS/ERD estimated the FPSO sound source levels without thrusters as 174 dB re 1 µPa·m.

5.1.3.2 FPSO using thrusters for heading control

For certain discrete activities, it may be advantageous to use the FPSO’s thrusters to hold the FPSO on an optimal heading (e.g., to prevent unplanned FPSO movements during helicopter approach). The proposed Torosa FPSO facility is a turret moored production vessel, with thrusters to assist with operational heading control. It is approximately 370 m long and 67 m wide with a draft of 16 m. Each of the Torosa FPSO’s thrusters is anticipated to be rated at 3 MW.

For the draft EIS/ERD, the underwater noise sound source level was estimated considering only the FPSO thruster power as the design of the FPSO thrusters were at a limited stage of maturity. It should be noted that the estimate considered the power of the thrusters at the time, which was two 5 MW thrusters. The assessment considered the two thrusters had a collective sound source level of 189 dB re 1 µPa·m, when the thrusters were used at 50% of maximum capacity.

The DNV Propellor Underwater Noise Modelling (DNV 2021) for the FPSO considered a more refined FPSO thruster design (2x3 MW) as well as general parameters for a typical propellor that may be used for the Torosa FPSO. The typical propellor parameters (revolutions per minute, number of blades and diameter) were based on indicative standard propellor designs currently considered by the proposed Browse Project. It should be noted that propellor vendor selection has not been finalized.

The DNV Propellor Underwater Noise Modelling study shows that the two thrusters with reduced power (i.e. 3 MW as opposed to 5 MW assumed in draft EIS/ERD) resulted in a collective sound source level for the FPSO of 183 dB re 1 µPa·m (inclusive of machinery noise). This is at the comparable thruster usage of 50% which aligns to the management approach outlined in **Section 6.1.2.**

Further, the DNV Propellor Underwater Noise study provided a preliminary analysis on mitigations that may be incorporated into the design of the FPSO thrusters to further reduce underwater noise. The study considered three key mitigation options:

- decrease propellor tip load factor from 100% up to 70%: Up to 5 dB reduction
- increase propellor diameter from 3 m to 4 m: Up to 8 dB reduction
- increase the number of propellor blades from 4 to 6: Up to 4 dB reduction.

It should be noted that the DNV Propellor Underwater noise study considered mitigations from a hypothetical perspective without engagement from propellor vendors, and therefore the technical feasibility of these mitigations have not yet been demonstrated.

FPSO Thruster Noise Mitigation

While selection of a vendor for the FPSO thruster for Torosa has not been completed, two short listed vendors were commissioned to further assess the underwater noise generated from proposed thrusters for the Torosa FPSO and the mitigations that may be possible through design optimisation. One of the vendors chose to participate and also used DNV to approximate the underwater noise from their thrusters.

The vendor found that One of the existing thrusters that is suitable for the application would be capable of operating at less than 174dB re 1 µPa·m (i.e. approximately the same amount of noise as FPSO machinery noise is estimated to generate), for the amount of thrust typically required by the Torosa FPSO. A number of design mitigations were considered. The thruster design mitigations considered included:

- Reduced propellor tip loading
- An increased propellor diameter
- An azimuthing design (i.e. thrusters whose direction can be controlled)

Designing the thrusters to be azimuthing allows for the blade curvature to be optimized for water flow in a single direction (as opposed to stationary thrusters, which must be able to flow water in both directions). The azimuthing blades are typically skewed, facilitating greater energy efficiency and reduced propellor tip loading.

While vendor selection for thruster underwater noise is not yet complete, an underwater noise limit for the Torosa FPSO thrusters will be set at 178 dB re 1 µPa·m.

5.1.3.3 Operational Supply Vessels (OSVs) operations supporting FPSO

During operations, support vessels will be required to transport goods to and from the Torosa FPSO. There are anticipated to be up to six supply runs per month at the Torosa FPSO, with offloading expected to take around six hours, but would occur for no more than 12 hours.

During support vessel operations, it will be necessary for the Support Vessel to use its dynamic position system to stay in a safe position during the supply operation. In rare conditions, the Torosa FPSO itself would also need to use its thrusters for heading control, if the supply vessel DP was insufficient to remain in a safe location for the activity to occur.

Individual sound source levels for OSVs servicing the FPSO are the same as for the PSVs servicing the MODU (refer **Section 5.1.1.3**).

During the majority of OSV resupply scenarios, it is anticipated that the Torosa FPSO thrusters will not be required for an OSV resupply to occur. However, there may be unusual weather conditions which require both the FPSO to use thrusters for heading control, and for the OSV to use its dynamic positioning system. The underwater noise sound source level for this activity has estimated based on the combination of the estimates for the individual underwater noise sources.

5.1.3.4 FPSO conducting condensate offtake

In the draft EIS/ERD, operational noise during offtake was described as having two noise sources during the offtake activity; the FPSO thrusters (at 2x5 MW) and an OSV's DP system. As described in **Sections 5.1.3.2** and **5.1.3.3**, in the draft EIS/ERD sound source level for these vessels were 189 dB re 1 µPa·m and 183 dB re 1 µPa·m, respectively.

Further, advice from Woodside's marine operational experts has confirmed that FPSO thrusters are seldom used during the offtake arrangement. Thrusters may be used temporarily to assist with offtake hookup (e.g. during the first two hours of the activity), however once the offtake tanker is hooked up and the OSV is maintaining tension on the offtake tanker, the FPSO does not use thrusters and instead weathervanes. Circumstances in which the FPSO would require considerable thrust are exceptional. Updated analysis by DNV for the proposed Browse Project based on the *Fugro Etive* as a representative analogue indicates a representative mean source level (MSL) of 185.5 dB re 1 µPa·m, when an OSV is in an offtake arrangement.

FPSO Condensate offtakes are routine events taking around 24 hours, and are anticipated to occur every 2-4 weeks.

Condensate offtakes will be subject to pre-start visual observations to ensure that no pygmy blue whales are present, however thrust may be required from the OSV at all times during the offtake (ot prevent offtake hose spills). Therefore, the OSV may not be able to deactivate thrusters upon sighting a whale. Condensate offtakes will not occur concurrently with OSV re-supply activities during periods when blue whale foraging is likely to occur.

The discrepancy between noise levels in the offtake arrangement and OSV resupply is based on different expected levels of thruster utilisation, which is based on marine operational advice. The azipull thrusters (at the stern) are primarily used for propulsion, as opposed to the bow/retractable thrusters which are primarily used for dynamic positioning. During OSV resupply, the propulsion thrusters are typically used less than the dynamic positioning thrusters. This is different from OSV use during offtake scenarios where the OSV applies force to maintain tension in the offtake arrangement, and therefore the propulsion thrusters are utilised at higher levels.

5.1.4 Subsea infrastructure operation (wellheads – choke valve)

Noise will also be generated during hydrocarbon extraction as a result of the operation of the well heads and subsea infrastructure. This infrastructure is located on the seabed in deep water (i.e. noise from operation of the TRD well heads is being generated at ~385m below the surface). In the draft EIS/ERD, the characterisation of underwater noise associated with subsea wellheads was based on McCauley (2002), who recorded noise from an oil producing subsea wellhead associated with the Cossack Pioneer FPSO and estimated the broadband source level to be 161.5 dB re 1 µPa·m (SPL).

Following development of this plan, further engineering investigation was completed to understand the benefits design mitigations may bring to noise from well heads. The outcome is summarised below. Noting the revised noise estimates, additional noise propagation modelling was also undertaken, shown in **Section 5.1.4.1**.

5.1.4.1 Well head noise mitigation design outcomes

To increase confidence in the characterisation of underwater noise associated with subsea wellheads, the two subsea equipment vendors currently considered for the procurement of the proposed Browse Project subsea infrastructure were commissioned to determine the amount of underwater noise associated with their specific well head design for the anticipated range of flow properties.

The two vendors provided an analysis of noise conducted in accordance with the 3rd edition of the IEC 60534-8-3 Standard. It should be noted that IEC 60534-8-3 is a recognised international standard for calculating noise from choke valves for safety management purposes in atmospheric conditions, with a confidence interval of +/- 5 dB based on empirical data. Appropriate factors were applied to account for the different acoustic impedance of air and seawater, as well as accounting for the different pressure reference values used for safety risk assessments and underwater noise environmental impact assessment.

Both vendors found that under all expected operational conditions, the expected underwater noise emitted by a subsea choke valve is below 161.5dB re 1µPa.m.

Further, both vendors were invited to propose further underwater noise emissions reductions techniques that could be applied to the wellhead or choke valve to reduce underwater noise. Vendors arrived at different potential solutions to mitigating underwater noise, with focus on application of either increased pipe wall thickness or acoustic insulation. The further investigation and application of these mitigations are discussed in **Section 8**.

5.1.4.2 Wellhead Modelling – 2022 Update

Following the wellhead underwater noise assessment by two subsea equipment vendors, a further modelling assessment has been conducted to re-estimate the underwater noise impact associated with the estimated underwater noise from wellheads, as well as the reduced estimated underwater noise that could be achieved with further mitigation. The results are presented in Appendix D

The wellhead underwater noise assessment considered configurations of up to six wellheads for both the unmitigated and mitigated underwater noise scenario. Six wellheads were selected (in comparison to the previous work that relied upon seven), given an update in the expected number of wellheads at each drill centre.

For the unmitigated underwater noise scenario, the loudest (on a broadband basis) indicative underwater noise spectrum estimated by either of the subsea vendors, corresponding to an underwater noise estimate of 158.2 dB re 1µPa.m. For the mitigated underwater noise scenario an indicative underwater noise spectrum of 147.3 dB re 1µPa.m was modelled, based on the same subsea equipment vendor’s estimates for a mitigated underwater noise scenario.

There is inherent conservative in this approach as it considers that all six wellheads are producing significant volumes of underwater noise simultaneously. Operationally, this is likely to be representative of only very small periods of time as there are operational constraints on the flow of wellheads from a single drill centre (for example, the maximum design flow of a flowline is less than the maximum design flow of all well heads producing simultaneously).

The noise modelling found that for six simultaneous unmitigated wellheads, underwater noise levels attenuate below 120 dB within 360m horizontal radius (R_{max}) and reach 200m up into the water column. For six simultaneous mitigated wellheads, underwater noise levels attenuate below 120 dB within 100m horizontal radius and reach 50m up into the water column (**Figure 5-1**).

It should be noted that at the current level of engineering design maturity, there remains some uncertainty in the estimated underwater noise source levels including benefits of identified mitigations. Further design work in FEED will be able to more accurately determine the underwater noise reduction estimate.

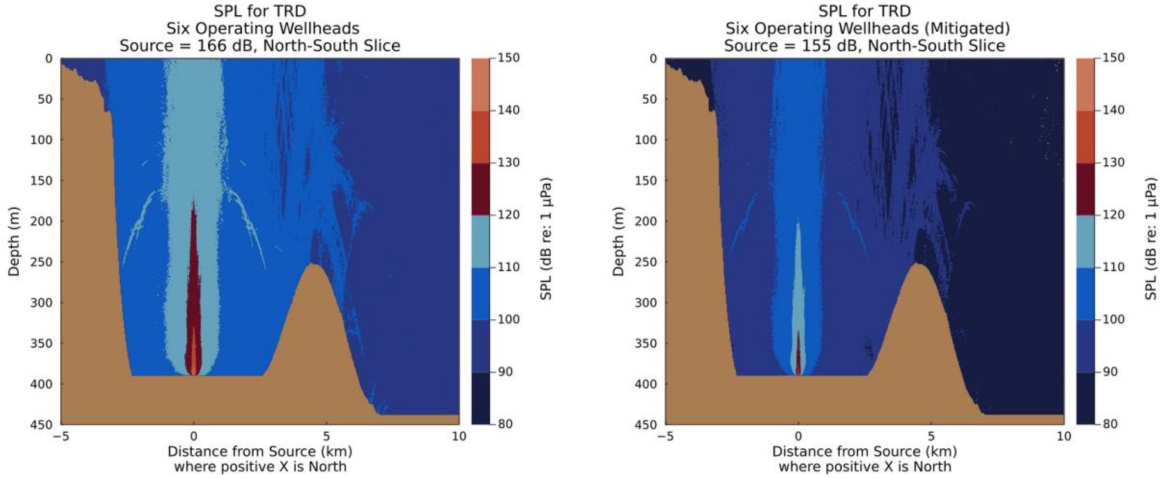


Figure 5-1 Estimated received levels within the channel at the TRD location based on a choke valve noise from six well heads. The first plot corresponds to the loudest estimate for unmitigated Browse wellheads at 158.2 dB re 1 μPa·m. The second plot corresponds to an estimate for mitigated wellheads at 147.3 dB re 1 μPa·m.

5.2 Impulsive Noise Sources

5.2.1 Driven Piling Activities

An acoustic modelling study developed for the draft EIS/ERD predicted that for piling for the FPSO mooring broadband (10 Hz to 25 kHz) sound energy at 10 m for each penetration depth will range from 184.6–199.4 dB re 1 μPa2 • s (inclusive of both IHC S-600 and IHC S-1200 hammers) with the peak sound energy concentrated in the frequency range 70 to 300 Hz, with levels from the pile at the shallowest modelled penetration depth having the highest energy. Although highly unlikely, impact piling may be required for mooring the MODU, however if required these piles are expected be significantly smaller than those used for the FPSO mooring system.

5.2.2 Vertical Seismic Profiling

Well bore seismic imaging techniques, including Vertical Seismic Profiling (VSP), use a small seismic airgun array. This assessment considered a 750 in^3 array operated at 6 m with a broadband (10–25,000 Hz) unweighted per-pulse SEL source level of 214 dB 1 μPa^{2}m^{2}s in the broadside and endfire direction (McPherson et al., 2019) The well bore seismic process is repeated as required for different stations in the well. Specifications for the 750 in^3 array are summarised in **Table 5-2**.

Table 5-2 Far-field source level specifications for the 750 in^3 array, for a 6 m operational depth. Source levels are for a point-like acoustic source with equivalent far-field acoustic output in the specified direction. Sound level metrics are per-pulse and unweighted.

Direction	Peak source pressure level ($L_{S,pk}$; dB re 1 μPa·m)	Per-pulse source SEL ($L_{S,E}$; dB 1 μPa^{2}m^{2}s)	
		10–2000 Hz	2000–25,000 Hz
Broadside	239.8	214.0	168.7
Endfire	240.1	214.1	175.3
Vertical	239.7	214.0	173.2
Vertical (surface affected source level)	239.7	216.2	176.1

5.3 Underwater Noise Modelling results

Noise propagation modelling results are presented within the EIS/ERD for a number of the key project activities/ To inform this management plan, noise propagation from additional project activities were modelled, or modelling revised, based on controls identified within this plan.

Supporting this modelling was detailed analysis on the noise (and potential mitigations) that would be generated by key proposed Browse Project activities including FPSO, MODU and OSV (DNV (2021 & 2022). The result of this analysis is presented in **Section 5.1.1** and **5.1.3**.

Updated estimates of the potential distance at which relevant sound exposure levels as relevant to pygmy blue whales (See **Section 3.5**) are presented in **Table 5-3**. Results are presented as the distance (maximum radius (R_{max})) from an activity at which these sound levels would potentially be received. Modelling outputs are from Green *et al* (2022a and 2022b, **Appendix A and B** respectively) and where necessary have been used to interpolate distances for activities where relevant analogues were available. All results are estimates as final activity/vessel selection has not occurred and would be updated and validated, as outlined in **Section 6.2**.

Activities which did not generate noise above 120dB anywhere within the Scott Reef possible foraging area are not presented here but are shown in the Browse to NWS Project draft EIS/ERD (as modelled by McCauley 2019).

Table 5-3 Summary of estimated SPL Maximum-over-depth horizontal distances to pygmy blue whale behavioural response threshold (120 dB re 1 µPa) and LF cetacean injury (TTS) threshold

Sound Source	**Distance to Behavioural Impact Threshold (R_{max})**	**Distance to TTS (injury – SEL24$_h$) threshold (R_{max})**	**Comments**
Subsea and FPSO Construction and Installation			
Offshore installation or flexible reel-lay vessel (e.g. flowline installation)	2.2 km [1]	0.46 km [1]	
FPSO Mooring and subsea Hookup (approx.. 5 vessels)	2.44 km [1]	0.53 km [1]	Cumulative impacts of up to five vessels considered
Rigid Pipelay Vessel, considering attendant support vessels (Used for BTL/IFL installation)	9.9 km [1]	2.16 km [1]	Cumulative impact of installation and support vessel considered
Drilling and Completion Activities			
MODU (moored)	0.49 km [2]	130 m [2]	
MODU (moored with OSV alongside for resupply)	2.3 km [2]	0.35 km [2]	Resupply predicted to take between 6 and 12 hours
MODU (Using Dynamic Positioning to hold steady position (DP))	4.5 km [2]	0.51 km [2]	
MODU (Using DP, with OSV alongside for resupply)	5.5 km [2]	0.58 km [2]	
Operations			
FPSO (No thrusters)	0.57 km [3]	90 m [3]	
FPSO (Offtake)	2.7 km [2]	0.63 km m [2]	
FPSO (OSV Resupply, no thrusters)	2.3 km [1]	0.5 km [1]	
FPSO (50% thrust)	2.8 km [2]	0.46 km [2]	Does not account for design mitigations.
FPSO (100% thrust)	8.8 km [3]	1.5 km [3]	
FPSO (50% thrust with OSV alongside)	3.9 km [1]	0.7 km [1]	FPSO thrusters would not typically be required, this is an unlikely activity. Does not account for design mitigations.
FPSO (50% thrust with design mitigations incorporated)	1.7 km [2]	220 m [2]	Estimate assumes target design mitigations are achieved

Sound Source	**Distance to Behavioural Impact Threshold (R_{max})**	**Distance to TTS (injury – $SEL24_h$) threshold (R_{max})**	**Comments**
FPSO (50% thrust with design mitigations incorporated and OSV alongside for Resupply)	2.5 km [1]	0.5 km [1]	Estimate assumes target design mitigations are achieved
Wellhead Choke Valves at each well centre	0 m (At surface) 0.36 km (At seabed) [4]	100 m	Does not consider design mitigations. Distance is per drill centre, which may include up to 6 wells online at any time
Wellhead Choke Valves at each well centre (with design mitigations incorporated)	0 m (At surface) 0.1 km (At seabed) [4]	20 m	Distance is per drill centre, which may include up to 6 wells online at any time
Offshore support vessel (In Transit)	2.3 km [3]	0.4 km [3]	
Impulsive Noise Source Activities			
Vertical Seismic Profiling	1.6 km [3]	1.7 km [3]	
Driven Piling	17.2 km [3]	29.5 km [3]	

[1] Green et al 2022b. JASCO Modelling Report #02742 (**Appendix B**).

[2] Green et al 2022a. JASCO Modelling Report #02589 (**Appendix A**).

[3] McPherson et al 2019. JASCO Modelling Report #01824

[4] Lazarides, C. (2022). Browse TRB & TRD Subsea Manifold LF Cetacean Noise Exposure Assessment. Browse Underwater Noise Modelling. Revision 0. Technical report by AMOG for Woodside Energy.(**Appendix D**)

5.3.1 Noise Modelling Uncertainty

All modelling inherently involves a degree of uncertainty and real-world outcomes can be expected to deviate from modelled results. Modelling underwater noise associated with sound sources is complex, as the amount of sound generated changes with different thruster utilisation (which may vary as metocean conditions and activity requirements change). It should also be noted that while 120 dB re 1 µPa has been selected as the behavioural response threshold in accordance with well-established impact assessment practice, behavioural response is not binary.

To manage these uncertainties, results presented in **Section 5.3** are presented with the following conservatisms:

- Modelling is based upon highly conservative estimates of the underwater noise sources, which are unlikely to be exceeded throughout field life. Therefore, modelling results should be interpreted as representative of worst-case conditions, not of normal year-round conditions. Further details are described in **Section 5**.
- *Example 1: MODU Dynamic Positioning Thruster Utilisation is modelled based on the amount of thrust required for the MODU to maintain station in worst case 1-in-1 year return period metocean events (non-cyclonic). These metocean conditions are unlikely to be representative of average year-round conditions.*
- *Example 2: OSV Thruster Utilisation during offtake is modelled based on marine advice on the limit of safe operational conditions (i.e. the maximum metocean conditions in which it is safe to conduct the activities). These metocean conditions are unlikely to be representative of average year-round conditions.*

- Modelling reports demonstrate that the extent to which noise travels before it attenuates below the behavioural response threshold is not uniform, and underwater noise may travel further in a particular direction due to unique geomorphology. Modelling reports manage this by showing graphical images of the extent of the ensonified areas, and by presenting two estimates of the distances to reach the behavioural response threshold, the R_{95} and the R_{max}. The R95 represents the 95th percentile distance to reach the behavioural response threshold of any direction from the point source. The Rmax represents the longest distance to reach the behavioural response threshold.
- All distances in this report are presented as Rmax and all ensonified areas have been presented as perfect circles with Rmax as the radius. In so doing, the report presents a highly conservative estimate of the actual ensonified area.

By presenting continuous underwater noise sources estimated based on their peak noise levels, and by presenting ensonified areas as perfect circles with a radius based on the maximum distance to the behavioural threshold, this report presents highly conservative estimates of the ensonified areas above the behavioural response thresholds. Results should be interpreted as absolute worst case scenarios in order to manage ongoing uncertainty associated with modelling results.

5.4 Cumulative TTS and PTS exposure Thresholds in the possible foraging area

The previous section describes the distances from noise sources to behavioural response thresholds based on underwater noise propagation modelling to determine the Sound Power Level (SPL; dB re 1μPa). The distances at which TTS and PTS may occur may also be determined using the same propagation modelling, but are instead calculated on the accumulated Sound Exposure Level (SEL; dB re 1 μPa2.s). The accumulated Sound Exposure Level is a metric of sound energy that a receiver accumulates over a period of time. Propagation modelling is able to determine the Sound Exposure Level that a whale may experience at any given location, provided the whale does not move over the period of exposure.

If the stationary whale is present for a longer period of time, then the distance within which they must remain stationary from the noise source to experience TTS or PTS increases. In environmental impact assessments it is convention to use a time period for assessment of 24 hours, corresponding to the TTS and PTS thresholds presented in **Table 3-2.** Therefore, when considering the distances at which TTS and PTS may occur for the purposes of environmental impact assessment, it is important to note that an animal at the edge of this distance must remain approximately stationary for the entire 24 hours in order to experience TTS/PTS respectively. Results of this modelling were summarised and presented in **Table 5-3**.

5.4.1 Animal Movement in Exposure Modelling

Distances to accumulated Sound Exposure Levels can be determined through sound propagation modelling, however dependence on a hypothetical stationary whale has limited relevance to marine fauna such as pygmy blue whales, which are highly mobile and therefore are highly unlikely to remain at the edge of the calculated TTS/PTS range for a continuous 24-hour period. TTS/PTS exposure distances based on propagation modelling alone therefore are of limited relevance to determining the probability of TTS and PTS exposure.

To account for this, animal movement can be incorporated into an exposure model, referred to as ANIMAT modelling. ANIMAT modelling considers representative animal density, movement and behavioural characteristics to model how a whale moves through the water column and then determine the Sound Exposure Level accumulated by the whale as it moves in relation to an underwater noise source. For the proposed Browse to NWS Project draft EIS/ERD modelling, detailed information on pygmy blue whales was derived from a range of sources that used multi-sensor tags to record fine-scale dive and movement behaviour (Owen *et al.,* 2016; AIMS unpublished data 2021), as well as satellite tags to record travel speed (Thums and Ferreira, 2021), refer to Cusano *et al.*, 2022 (Appendix C).

It should be noted that the ANIMAT modelling does not consider a behavioural (avoidance) response to the underwater noise source, which is highly conservative, particularly if the noise is causing injury.

As ANIMAT modelling is a separate exercise from underwater noise propagation modelling, ANIMAT modelling has only been conducted on some of the key underwater noise sources anticipated to occur over the life of the Project (Cusano *et al*. 2022 – **Appendix C**):

- Torosa FPSO (no thrusters)
- Torosa FPSO Offtake
- MODU using DP at TRD[4]
- Cumulative Scenario – Torosa FPSO Offtake and MODU using DP[4] at TRD

ANIMAT modelling results are presented in two different metrics:

- The 95th Percentile Exposure Range [ER_{95}]: This presents the closest approach distance to the noise source that 95% of the simulated receivers whose modelled accumulated Sound Exposure Level exceeded the TTS or PTS threshold. Ie *is the 95th percentile estimate of how close an animal must come (instantaneously) to a noise source to experience TTS/PTS once animal behaviour is accounted for.*
- The Probability of Exposure (in the 95th Percentile Exposure Range) [PER95]: This presents the proportion of simulated receivers that entered the 95th Percentile Exposure Range whose modelled accumulated Sound Exposure Level exceeded the TTS or PTS threshold. Ie *is the conditional probability estimate that an animal which enters the 95th Percentile Exposure Range (instantaneously) will experience TTS/PTS.*

ANIMAT modelling results from Cusano *et al*. 2022 (**Appendix C**) are summarised in **Table 5-4**.

Table 5-4 Summary of estimated 95th Percentile Exposure Ranges and Probabilities of Exposure (in the 95th Percentile Exposure Range) for Pygmy Blue Whale ANIMATs. Results present the worst case ANIMAT simulations, considering North Bound Migration, South Bound Migration and Foraging pygmy blue whales.

Thresholds (NMFS 2018)[5] (dB re 1 μPa² · s)		**MODU on DP at TRD**		**Torosa FPSO (No thrusters)**		**Torosa FPSO Offtake**		**MODU on DP at TRD + FPSO Offtake**	
		ER_{95}	**P_{ER95}**	**ER_{95}**	**P_{ER95}**	**ER_{95}**	**P_{ER95}**	**ER_{95}**	**P_{ER95}**
PTS (SEL_{24h})	**179**	0m	0	0m	0	10m	33%	10m	12%
TTS (SEL_{24h})	**199**	30m	53%	0m	0	50m	46%	50m	34%

The results in **Table 5-4** demonstrate that while estimates of Accumulated Sound Exposure Level Ranges determined by sound propagation modelling show a larger distance over which the TTS and PTS thresholds may be exceeded for a whale that is present and stationary for 24 hours, when animal behaviour is accounted for the risk of TTS and PTS, ANIMAT modelling shows of all simulated

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[4] Noting that since the ANIMAT modelling was undertaken, mitigation measures exclude a MODU station keeping using Dynamic Positioning at Torosa during Peak Pygmy Blue Whale season. This notwithstanding, the example remains a useful datapoint to inform assessment.

[5] It should be noted that since the underwater noise modelling was undertaken, the National Marine Fisheries Service updated the thresholds for PTS (197 dB re 1 μPa2 · s) and TTS (177 dB 197 dB re 1 μPa2 · s) (NMFS 2024). The minor change in thresholds is not expected to alter the outcome of the impact assessment in relation to underwater noise and therefore thresholds remain unchanged in the context of the noise modelling results.

whales exposed to TTS/PTS, 95% had come within 50m/10m (respectively) of the vessel sound source.

The activity with the highest potential for PTS/TTS (considering duration and frequency of occurrence and noise size) was the FPSO Offtake Scenario. The TTS range for this activity as determined by sound propagation modelling considering a stationary receiver over 24 hours is 630 m. ANIMAT modelling demonstrates that most (95%) of simulated whales that would be exposed to sound exposure level accumulation above the TTS threshold (i.e. could experience TTS injury) came within 50m of the noise source – a significantly smaller exposure distance.

5.4.2 Consideration of PTS/TTS Likelihood

This section explains the application of the ANIMAT modelling to determine likelihood of causing injury (i.e., PTS/TTS) to a pygmy blue whale. Prior to considering mitigative controls, it is important to also consider the likelihood of pygmy blue whale presence and behaviours (migrating and foraging) with reference to activity locations (i.e., Torosa FPSO) and the possible foraging area at Scott Reef, refer to **Section 4.5.1**.

In considering the role of controls in determining the likelihood of causing injury**, Section 9** describes the Noise Mitigation Plans that will apply to proposed Browse Project Activities with mitigable underwater noise. Under the Noise Mitigation Plans, crew staffing these activities are required to monitor for, and react to detection of (if practicable), an approaching pygmy blue whale. Monitoring distances presented in **Section 9** are significantly larger than the approximately 10m or 50m distance (ER_{95}) that a pygmy blue whale would typically need to come within a noise source to experience an accumulated Sound Exposure Level that exceeds the PTS or TTS thresholds, respectively.

It is considered highly unlikely that a pygmy blue whale would choose to travel towards the noise source (given the distance a which behavioural response occurs is anticipated to exceed the TTS/PTS ER_{95} range considerably), and it is further considered that implementation of the Noise Mitigation Plan controls (i.e. deactivation of vessel propulsion systems or FPSO thrusters when practicable to do so) would substantially reduce the likelihood of the pygmy blue whale arriving within 50m of the noise source without the source being deactivated or reduced. For activities where deactivating the noise source is a practicable option under a Noise Mitigation Plan, PTS or TTS exposure to a pygmy blue whale is therefore considered to be highly unlikely and is not assessed further.

For activities where the ER_{95} distance is either modelled (Torosa FPSO machinery only) or anticipated to be zero based on interpolation of modelling results (MODU machinery only and subsea wellhead choke valves – noting their sound source level is lower than the FPSO machinery only sound source level), PTS or TTS exposure is also considered to be highly unlikely, and is not assessed further.

The activities where deactivating a noise source is not an option and are anticipated to have an ER_{95} >0m include the FPSO Offtake (OSV) and the Rigid Pipelay Vessel. The Rigid Pipelay Vessel is not assessed further, as this one-off activity is short term in duration and is targeted to occur outside of Peak Pygmy Blue Whale season.

Given that:

- The eastern extent of the possible foraging area is considered in this plan to have a low likelihood of foraging by pygmy blue whales as compared to the western extent of the possible foraging area, as outlined in **Section 4.5**.
- For a pygmy blue whale to experience PTS or TTS from the OSV during an offtake arrangement, it must typically come within 10m or 50m (ER_{95} range) of the OSV's propulsion system respectively.
- FPSO Offtake will be conducted under a Noise Mitigation Plan (refer **Section 9**), requiring crew to monitor for Pygmy Blue Whales within 3 km for 30mins. It is not credible that a pygmy blue

whale could reside within 50m of the offtake vessel without detection, and then be exposed to a high accumulated Sound Exposure Level as propulsion commences.

- The behavioural response range for the FPSO Offtake scenario (driven by the OSV) is approximately 2.7 km. Therefore, in order for the whale to enter a distance within which it is likely to be exposed to PTS/TTS, it must travel at least 2.6 km beyond its behavioural response threshold.
- FPSO offtakes are an intermittent activity, occurring up to once per fortnight. Assuming the peak Pygmy Blue Whale periods include the entire months of May, June and November, there is only approximately up to 6 days of the year where pygmy blue whales are likely to be regionally present in order for this risk to occur.

It is considered that the risk of a pygmy blue whale being exposed to TTS or PTS from an FPSO Offtake activity with the proposed Browse Project activities is highly unlikely.

In summary, having considered the full range of vessel and facility underwater noise sources in the context of ANIMAT modelling, it is considered that the risk of a pygmy blue whale being exposed to TTS or PTS from any vessel associated with proposed Browse Project activities is highly unlikely.

6. MANAGEMENT FRAMEWORK

This section outlines the approach to the management of the potential underwater noise impacts on pygmy blue whales that will ensure that environment performance objectives for the Project as outlined in **Section 3.1** are achieved.

This management approach has been developed based on the Australian Government guidance on Blue Whale Conservation Management Plan – Frequently Asked Questions document. This management approach has been applied to develop the proposed Design Features and Management Measures, including their timing and reporting, which are presented in **Section 8**.

Also presented within adaptive management actions that will be implemented should the mitigation and management measures not achieving specified performance standard.

The management approach incorporates the following key framework components:

- Apply **Management Measures** in accordance with the hierarchy of controls, based on scientific monitoring results;
- Apply **Adaptive Management** in response to new information to ensure the management measures are appropriately applied;
- Conduct **Scientific Monitoring** to inform application and verify appropriateness of management measures in achieving stated outcomes;

A review of industry best practice management approaches is also provided for context.

Scientific Monitoring

The key objectives of the Scientific Monitoring program are as follows:

- To verify and further understand the seasonality, residency time, behaviours and relative abundance of the EIO pygmy blue whale population utilising the possible foraging area at Scott Reef.
- To identify the habitats within the Scott Reef possible foraging area that are likely to support foraging opportunities to inform the application of the mitigation hierarchy to underwater noise.

The Pre-Operational Scientific Monitoring Program is further detailed in **Section 7**.

6.1 Application of the Hierarchy of controls.

In accordance with Woodside's HSE risk management procedures, risk reduction measures are prioritised and categorised in accordance with the hierarchy of controls, where risk reduction measures at the top of the hierarchy take precedence over risk reduction measures further down. The use of the hierarchy demonstrates that underwater noise impacts have been minimised by first considering those controls which would be most effective at managing underwater noise. The proposed design features and management measures **(Section 8)** have been developed using the hierarchy of controls described in **Table 6-1**.

Table 6-1 Hierarchy of controls applied to management of underwater noise within this plan

Control	Definition	Application
Avoidance	Avoid generating noise when or where pygmy blue whales are likely to be present.	Construction activities will avoid certain areas at certain times, informed by scientific monitoring to determine likelihood of whale foraging occurrences. See Section 6.1.1 for an overview of how avoidance measures applied in this plan.

Control	Definition	Application
Minimisation	Use engineering controls & design to reduce the sound source levels associated with activities. Substitute high noise generating activities with quieter alternatives.	Design long term, new build infrastructure with a focus on noise minimisation. Use of mooring instead of dynamic positioning, suction piling instead of hammer piling etc. See Section 6.1.2 for an overview of how 'minimisation' of noise is applied in this plan.
Detection and Mitigation	Where an activity cannot be eliminated, substituted or reduced such that noise generated is below behavioural response thresholds), apply operational mitigations.	Apply Noise Mitigation Plans (NMPs) (refer **Section 9**) to monitor for, and react to detection of (if practicable), an approaching pygmy blue whale in accordance with spatio-temporal management principles. See Section 6.1.3 for an overview of how 'mitigations' are applied in this plan

6.1.1 Avoidance

Project activities will avoid times of the year when blue whale foraging is likely to occur (at the relevant locations) whenever feasible. It is feasible to apply Avoidance periods for:

- Drilling and completion activities;
- Installation of subsea flowlines and Inter-Field Life;
- Installation of pilings or moorings; and
- Vertical Seismic Profiling;

It is not feasible to move permanent infrastructure outside of the possible foraging BIA so as to avoid operational activities when blue whale foraging is likely to occur (refer **Section 8.6**).

Applying Avoidance controls inherently requires decision-making regarding the times for an activity to avoid at the relevant activity locations (e.g. the times a MODU will avoid drilling at drilling location 'TRA'). The times when blue whale foraging is likely to occur will be determined in by the Scientific Monitoring process outlined in **Section 7**.

6.1.2 Minimisation

Minimisation controls will be applied where practicable to underwater noise sources that ensonify the Scott Reef Possible Foraging BIA (above cetacean behavioural response thresholds) at all times of the year.

For Project execution activities:

- Any MODU drilling at Torosa or Brecknock must not use a dynamic positioning system other than when transiting to/from the drilling location, unless for safety or emergency purposes. Drilling is not to occur while DP systems are active.
- Vessels will be required to identify specific measures that are available or will be in place to reduce noise. These are to be included in a noise mitigation assessment report.
- Impact Piling will only be used if other forms of pile installation (including suction piling) are demonstrated not to be feasible.

For permanent new build infrastructure to be installed within the Possible Foraging BIA, design targets for underwater noise are as follows:

- The Torosa FPSO Thrusters (178 dB re 1µPa.m): FPSO Thruster noise limit can be achieved through various options, including selecting an Azimuth thruster, designing a low-noise propeller (e.g. increasing propeller diameter, blade number, and reducing tip loading), and oversizing the thruster.
- The Torosa FPSO Machinery (174 dB re 1µPa.m): FPSO Machinery noise limit can be achieved through various options, including appropriate location of equipment, application of isolations/dampeners between equipment and the hull, and specifying low-noise equipment.
- The Well Head Choke Valves (161.5 dB re 1µPa.m): Well Head Choke Valve noise limit can be achieved through various options, including the application of acoustic insulation and increased material thickness.

An independent vessel Classification Society (e.g. DNV, Lloyds) will be engaged throughout the design process to verify that the Torosa FPSO thrusters and machinery are designed such they are capable of achieving low noise targets. To verify the outcome of the design process, a ‘low noise classification’ will be sought for the FPSO.

Operation of the Torosa FPSO Thrusters can be further mitigated (power limited, not used or turned off) during Project operations to meet underwater noise design limits, if required.

6.1.3 Detection and Mitigation (Noise Mitigation Plans)

Detection and Mitigation controls will be applied to all underwear noise sources which may ensonify the Possible Foraging BIA above the cetacean behavioural response threshold, at all times when a whale could be present. The only activity for which this is not practicable is the operation of the subsea wellheads due to the depths at which they operate and absence of reactive mitigations.

The purpose of Detection and Mitigation measures is to prevent unacceptable impacts to pygmy blue whales that may travel close to Project activities in order to forage. Upon detection of a whale within an area that modelling indicates the whale may be disturbed, the relevant Project activity will cease/pause high noise generating activities (such as vessel dynamic positioning, MODU drilling or FPSO thrusters).

The specific detection measures, as well as the specific noise sources that can be ceased/paused, will differ depending on the activity. Detection measures will also be scalable based on activity timing and location, as well as whale observations during the activity. The specific detection and mitigation measures will be outlined in Noise Mitigation Plans (NMPs) that will be specifically developed for the activity. For more detail, refer **Section 9**.

6.2 Adaptive Management

6.2.1 Verification of periods used to define ‘avoidance’ periods

To provide ongoing confidence that Avoidance periods as described in **Section 6.1.1** are accurately defined, an ongoing scientific monitoring program shall be implemented prior to and during operations relying on these measures. A minimum of three years of representative data is required to inform such decisions. The operational monitoring program will maintain a robust understanding of pygmy blue whale seasonality/foraging area use and understand changes over time.

Furthermore, all vessels operating within the Possible Foraging Area will operate under a Noise Mitigation Plan. As part of operating under NMPs, all vessels will report whale observations while in-field.

Observation data from both the operational monitoring program as well as gathered under NMPs shall be regularly reviewed to ensure that Avoidance periods are correctly defined.

6.2.2 Verification of sound source levels used to inform impact assessment

Underwater noise source design targets have been established for the Torosa FPSO Thrusters and Torosa Well Head Choke Valves. Estimates as to what magnitude of noise will result after application of these mitigations has informed the impact assessment outlined in this plan.

To provide confidence that underwater noise source limits have been achieved, in-field verification of key underwater noise sources shall be conducted within the first year of the noise source being operational. In the case of the Torosa FPSO, an independent classification society will be engaged to inform the design process to ensure design targets will be achieved and certify the design as being capable of achieving the set targets.

In the event that:

- Torosa FPSO Thrusters exceed the source levels outlined in **Section 6.1.2**, noting noise estimates will have been performed during the design phase, then the FPSO Thruster maximum thruster use limit will be reduced such that thruster noise remains within underwater noise limits. This calibration can be achieved as part of the verification exercise.
- An independent vessel Classification Society (e.g. DNV, Lloyds) will be engaged throughout the design process to verify that the Torosa FPSO thrusters and machinery are designed such they are capable of achieving low noise targets. To verify the outcome of the design process, a 'low noise classification' will be sought for the FPSO. A final assessment of the predicted noise footprint of the vessel will be reviewed against targets outlined in this plan.

6.2.3 Mitigation (Noise Mitigation Plans)

Observation and shutdown zones will be established in each relevant activity's Noise Mitigation Plan. Shutdown zone size will be determined based on the distance to the cetacean behavioural response threshold from the relevant noise source, as determined by underwater noise modelling.

To provide confidence that shutdown zones have been correctly described, in-field verification of key underwater noise sources (MODU, subsea construction vessel, FPSO), will be conducted within the first year of the noise source being operational. In-field verification of underwater noise sources will include acoustic monitoring of the underwater noise source for a sufficient period of time to confidently predict underwater noise source levels associated with the activity, including any temporary activities (e.g. OSV offload for a MODU).

If in-field verification of key underwater noise sources demonstrates that the underwater noise source is substantially different than expected, then the Shutdown zones in the relevant Noise Mitigation Plan will be revised with updated underwater noise modelling results.

6.3 Review of Framework Against Industry Best Practice

A synthesis of noise reduction guidance, frameworks, implementation program and projects that have been adopted or otherwise endorsed by intergovernmental policy fora, individual governments and international agreements/organisations by Chou *et al* (2021) provides insights into international best practice noise mitigation measures. Chou *et al*. (2021) differentiated industrial noise as (1) incidental and (2) deliberate. Incidentally radiated noise sources include those generated by oil and gas activities and associated vessel traffic. In contrast, deliberately radiated noise sources include those from airguns associated with oil and gas seismic surveys.

Noise mitigation strategies highlighted by Chou *et al* (2021) and Bröker (2019):

- Spatio-temporal mitigation strategies including avoidance of noise-generating activities in areas or during times of high animal density, including biologically important areas such as breeding and feeding.
- Quieting technologies including design specifications and regular maintenance of propeller, hull and onboard machinery to reduce cavitation and surface roughness.

- Other mitigating methods such as developing noise exposure limits and acoustic impact thresholds for different species, use of acoustic deterrent devices (ADDs), reducing ship speed and soft-start or ramp up procedures for seismic surveys to prevent physical injury.
- Exclusion zones as a key mitigation measure to reduce the likelihood of auditory damage due to exposure to high sound levels. Exclusion zones are zones around a source sound that are monitored for presence of marine mammals by marine mammal observers and passive acoustic monitoring systems. Such safety or injury zones are mainly used during seismic survey operations to avoid injury to marine mammals. Exclusion zones to mitigate behavioural responses are not a common practice for seismic surveys, however there are examples where such mitigation actions have been applied such as for the small population of western gray whales off Sakhalin. There are no documented industry case studies for the application of exclusion zones for long-term continuous noise sources and the mitigation of behavioural response impacts.

  Furthermore, noise mitigation measures are based on scientific exposure criteria that are an evolving science and will need to be reviewed and incorporated into the adaptive management approach of the proposed Browse Project. Southall (2021) in discussing the evolution of the marine mammal noise exposure criteria including temporary and permanent threshold shift onset levels and a descriptive spectrum of behavioural response severity from benign to lethal, highlights the needed ongoing requirement for research to build on available data and continue to improve criteria.

7. SCIENTIFIC MONITORING PROGRAM

7.1 Overview

As outlined within Section 6.3.8 of the draft EIS/ERD and Section 4.4.2 of the Supplement Report to the draft EIS/ERD, scientific monitoring and verification programs have been proposed in relation to pygmy blue whales and underwater noise.

A scientific monitoring program is planned, to confirm and update baseline data on the distribution, relative abundance, seasonality and behaviour of pygmy blue whales within the possible foraging area (and surrounds) at Scott Reef (refer to **Section 9**). Ongoing data acquisition at relevant times throughout the proposed Browse Project will be a key component of the scientific monitoring program. The program will continue monitoring pygmy blue whales and confirm sound source levels of project activities.

The key objectives of the pygmy blue whale monitoring program are as follows:

- To verify and further understand the seasonality, residency time, behaviours and relative abundance of the EIO pygmy blue whale population utilising the possible foraging area at Scott Reef.
- To identify the habitats within the Scott Reef possible foraging area that are likely to support foraging opportunities to inform the application of the mitigation hierarchy to underwater noise.
- Investigate technology to improve real-time detection of pygmy blue whales.

These objectives will be achieved through the implementation of three key monitoring programs.

- Pre-operational monitoring program (**Section 7**) – This scope will focus on characterising and measuring the ambient soundscape (physical, anthropogenic and biological), as well as determining the presence, spatial and temporal distribution of whale species within the Development Area (including foraging and migratory BIAs). This monitoring program will address the commitment to verify and further understand the seasonality, residency time, behaviours and proportion of the EIO pygmy blue whale population utilising the possible foraging area at Scott Reef. Results will be utilised as part of an adaptive management program (**see Section 9**)
- Operational monitoring Program – ongoing passive acoustic monitoring and oceanographic monitoring to track seasonality and predict peak periods within the northbound and southbound migratory seasons.
- Real time detection – A program to identify and implement viable real-time detection systems for pygmy blue whales that can be implemented into this Management Plan to improve outcomes where observation is relied upon (e.g. application of Noise Mitigation Plans, **Section 9**).

7.2 Pre-Operational Monitoring Program (Indicatively 2023 – 2028)

A pre-operational monitoring program will be designed and implemented to understand and maintain currency of pygmy blue whale (and other whales) movement and behaviour within and in proximity to the proposed Browse Project. Pre-operational data collection, ongoing monitoring and real-time detection of marine mammals with a focus on pygmy blue whales will inform the operational basis of management controls and mitigation to support the management approach.

The two primary objectives of the pre-operational monitoring programs are to:

- To verify and further understand the seasonality, residency time, behaviours and relative abundance of the EIO pygmy blue whale population utilising the possible foraging area at Scott Reef.
- Identify the habitats within the Scott Reef BIA that are likely to support predictable aggregations of prey to ensure spatial management areas are appropriately defined.

The key components identified as part of the pre-operational monitoring program are presented in **Table 7-1**. The passive acoustic monitoring (PAM) will be designed and executed to obtain information on the ambient soundscape and the presence of pygmy blue whales (and other whales).

Table 7-1 Overview of pre-operational monitoring program applicable to Pygmy Blue Whales

Type	Parameters	Locations	Timing
Verify and further understand the seasonality, residency time, behaviours and relative abundance of the EIO pygmy blue whale population utilising the possible foraging area at Scott Reef			
Passive Acoustic Monitoring – seabed landers at specific locations	Presence and timing of pygmy blue whales based on vocalising individual whales	Lander deployment design to optimise detection of pygmy blue whales on western and eastern entrances and within the Scott Reef Channel and eastern extent of the possible foraging area. Lander deployment design to optimise detection of pygmy blue whales within the migratory BIA overlap with the Calliance and Brecknock facility locations.	At least three years out from commencement of any Project development activities. Note, this program has been in place for 18 months.
PAM - autonomous underwater vehicles (AUVs) such as gliders or Autonomous surface vessels (ASVs) for regional context and the relative importance of the Scott Reef possible foraging area	Presence, distribution and timing of pygmy blue whales within and outside the Scott Reef possible foraging area based on vocalising individual whales	Possible foraging area at Scott Reef Migratory BIA area overlap with Calliance and Brecknock Migratory BIA area overlap and proximity to Browse trunkline route	At least three years out from commencement of any Project development activities.
Vessel-based visual and drone-based surveys	Presence and timing, behaviour of pygmy blue whales Life-stage, sex and health of pygmy blue whales sighted	Specific to Scott Reef channel area and eastern extent of the possible foraging area.	Commence three years out from commencement of any Project development activities Five years of bi-annual survey trips of the Scott Reef channel area, targeting peak north and southbound migratory periods (based on PAM records when available, intelligence gathering from other studies, tourism activities in Timor Leste etc.
Telemetry	Distribution, movement and behaviour – horizontal and vertical	Satellite tagging of pygmy blue whales, such as: Limpet tags to track long distance migrations Archival pop-off tags (miniPAT) to record diving behaviour	Commence three years out from commencement of any Project development activities

Type	Parameters	Locations	Timing
Identify the habitats within the Scott Reef possible foraging area that are likely to support predictable aggregations of prey to ensure spatial management areas are appropriately defined.			
Oceanographic sampling and krill (pygmy blue whale prey) availability	Water column profiling and hydroacoustic backscatter monitoring to detect and predict krill abundance, occurrence - depth in water column and distribution (spatial and temporal scales)	Scott Reef channel area and surrounds (wider Browse basin)	Commence three years out from commencement of any Project development activities Bi-annual during shoulder and peak periods for north and south bound migrating pygmy blue whales
Mapping/modelling of regional productivity as a proxy to prey (krill) location and availability	Remote sensing techniques to identify environmental drivers of prey availability and prediction of krill blooms in space and time or proxy to indicate lead time to krill blooms	Regional – targeting known and possible foraging areas	Commence three years out from commencement of any Project development activities

7.2.1 Passive Acoustic Monitoring

Moored omni-directional acoustic recording ‘stations’ will be deployed in order to quantify the soundscape within the proposed monitoring locations. Bottom mounted recorders are proposed for this long-term monitoring application as this configuration leads to the most stable platform, minimising mooring noise although alternative configurations with equivalent outcomes may be included.

A determination of the final recording station design will be made once final monitoring locations are determined as water depth is a key consideration for the equipment selection and design.

The proposed duty cycle for the recorders is an important consideration for the monitoring program. The duty cycle must allow for the quantification of both ambient soundscape and marine mammal presence equally well. A reduction of the duty cycle impacts negatively on the ability to detect cetaceans and determine call rates. Generally, more frequent short listening periods improve the accuracy of daily presence estimates of cetaceans. Overall, subsampling effects are most pronounced for low and/or temporally clustered vocal activity (Thomisch *et al*. 2015).

A sampling rate sufficient to acquire acoustic frequencies up to 30 kHz is required to detect baleen whales and to measure anthropogenic and geophony. In order to monitor for the presence of toothed whales, a sampling rate that allows at least 100 kHz to be resolved is proposed. A minimum 15-minute duty cycle is proposed. This duty cycle will comprise of a minimum of 50% recording time for baleen whales along with sampling at higher frequencies for odontocetes (to optimise detection of beaked whales and similar species that have relatively short detection distances) and the smallest period of sleep that allows the recorder to function for the desired deployment period.

Initially, the recorder servicing trips will be conducted every 6 months to validate data quality and to ensure that the monitoring is meeting the desired objectives. After approximately the first three deployments (dependent on results) service trips may be conducted annually.

7.2.2 Sampling Design

A determination of the specific number and location of the acoustic recording ‘stations’ within the monitoring locations (e.g. Torosa and Brecknock/Calliance) will take into consideration a number of key factors during the planning and execution phase. The following sampling design process will be implemented during the planning and execution phase of the monitoring program.

1. Compilation and analysis of relevant environmental data for the Browse Development Area. This includes current data, bathymetry and sound speed profiles. These parameters have a strong influence on ambient noise.
2. Modelling to assist in determining optimal recorder locations.
3. Mooring designs and modelling of mooring performance.
4. Recorder configuration design (duty cycle configuration, sampling frequency).

Expert advice will be sought in developing the design of the monitoring program to ensure any outcomes meet the objectives of the program and will be statistically valid.

7.2.3 Challenges for Monitoring and Detection of Pygmy Blue Whales

Pygmy blue whales migrate and forage in oceanic areas of Western Australian waters that are generally offshore and remote posing challenges to the operational feasibility of monitoring as outlined:

- Despite being one of the largest known animals to have ever existed they are elusive, spending long periods underwater, taking short surface intervals (to breathe) and move over vast areas of remote, deep offshore oceans.
- Populations were severely depleted by commercial whaling with many only recently discovered, together with population specific important life-stage habitats and locations only recently identified or are yet to be discovered.
- Population recovery and quantitative estimates on numbers are not accurately known, only estimated from passive acoustic detection and little information exists on population structure.
- The numbers of pygmy blue whales migrating through the Scott Reef possible foraging area are only a subset of the EIO pygmy blue whale population and detection within the vast area of the BIA will present challenges in optimising survey designs.
- Telemetry studies have confirmed individual whales undertake extensive transboundary migrations that intersect with major shipping lanes, commercial fishing activities and existing offshore oil and gas facilities that pose current pressures and threats to pygmy blue whale populations.

7.3 Operational Monitoring

Components of the pre-operational monitoring program such as the passive acoustic monitoring will be maintained for the construction and operational phases of the proposed Browse Project.

The exact components and elements of the operational monitoring program will be determined following a review of the implementation of the pre-operational monitoring program. As per **Section 7.4.1**, an expert panel will be utilised to input into the design of this ongoing monitoring program.

7.4 Technology Investigation for Real-Time Detection of Pygmy Blue Whales

A key component of the site-specific activities for the construction and operational phases of Brecknock/Calliance and Torosa is real-time detection of pygmy blue whales for specific activity Noise Mitigation Plans (NMPs). As detailed in **Section 9**, the NMPs require qualified marine mammal observers for visual monitoring of whales and as such, operations are restricted to daylight hours. Advancements in marine mammal detection technology may simplify the marine mammal observation process and provide an opportunity to reduce reliance on visual identification techniques. To date, technological detection methods have been explored as complementary or alternative methods to visual monitoring in low visibility conditions for seismic surveys. Verfuss *et al*. (2018) reviewed such methods and concluded that the efficiency will depend on animal behaviour and environmental conditions but using a combination of complementary systems generally improves the overall detection performance. A component of the scientific monitoring program will include a research and development program on real-time detection technologies with the goal of operationally feasible, cost-effective and robust real-time detection technology for the proposed Browse Project.

Advances in technology and innovation are expected to enable such innovations such as connection of PAM systems to communications systems within the subsea infrastructure to provide real time information back to the FPSO. This data will be used to inform and improve scientific knowledge and also be used to inform management measures.

Results of the passive acoustic monitoring and visual observation surveys during the pre-operational monitoring program will be used to inform the design and location of the ongoing passive acoustic monitoring program. Furthermore, data processing advancements using AI may be such that results of an ongoing monitoring program can be near-to or real-time and support verification of the spatial and temporal controls and mitigation management measures to prevent noise impacts to pygmy blue whales.

Real time monitoring and detection of vocalizing whales, through the use of an underwater listening station (ULS), is already being used in Boundary Pass (50 km south of Vancouver) by the Vancouver Fraser Port Authority. The ULS comprises installed listening stations that send data back to an interpretation system, providing real time analysis both of the noise signature of passing vessels and detection of vocalizing whales to inform real time adaptive changes to shipping activities.

Methods of real-time whale detection technology that are currently implemented and/or under development that may be considered for further investigation are listed below.

Table 7-2 Real-time whale detection technologies for further investigation

Detection method	Benefits	Constraints
Drone surveillance for monitoring of exclusion zones	Identify whale presence, species and behaviour such as foraging Detection can reduce likelihood of encountering pygmy blue whales at a distance that may cause injury or behavioural response Leverage data (photographic imagery) for scientific studies on pygmy blue whales	Drone equipment suitable for offshore flying conditions and the requirement for dedicated drone pilots Type of drones (commercial to military use) determines flying range and time which varies from limited (range is within sight and duration times short) to extended (distance range of 100s km and flight durations of 24-28 hours). Type and feasibility of operation to support activity specific monitoring requires further investigation
Passive acoustic monitoring – landers, autonomous underwater vehicles (AUVs) and autonomous surface vehicles (ASVs)	AUVs deployable from support vessels and can be programmed on specific routes Based on signature vocalisation can detect whale species	Data upload and processing delays access to whale detection information. Technology relies of whale vocalisation for detection and pygmy blue whale vocalisation for Western Australia currently not well understood in terms of relating calls to population structure and behaviour such as foraging.

Detection method	Benefits	Constraints
Infra-red thermal imaging	Can be used at night and periods of low visibility. Can increase likelihood of detecting whale presence BRII project – industry, NOPSEMA and AAD supporting concept development of such technology for whale detection	Limitations on detection distance/depth, interpretation of data (identification of whale type for example) and practicality of implementation.
RADAR	360° detection zone Can be deployed from MODUs and FPSOs – fixed top-side infrastructure or support vessels	Requires whales to be on surface for detection Limited to short range detection (<1 km) in optimal sea conditions Moderately affected by high sea state, fog and heavy rain Issues with detection of false positives from wave crests, surface debris and buoys Inability to differentiate between whale species

7.4.1 Expert Panel Assurance

Given the complexity of the PBWMP it is appropriate to ensure expert advice is sought and incorporated into the management program. Therefore, following project FID, an expert panel will be established to ensure that the applied controls provide a high degree of certainty that the environmental objectives of this Management Plan can be met.

A key component of the Expert Panel's responsibilities will be to scientific monitoring program implemented and any monitoring results used to define periods where PBW foraging is likely to occur. They will also have a role in ensuring specific environment performance outcomes are being achieved and environment performance standards are appropriate.

Experts forming this panel will be selected based on their demonstrated relevant experience and independence from implementation of the activity. Experts should have at least five but preferably ten years experience in the relevant disciplines including evidence of having contributed to the peer reviewed knowledge base. Participants should not be directly involved in contributing to elements of the program. Experts will preferentially have expertise in the fields of either baleen whale ecology or underwater noise impacts & management.

Expert review involvement will be at least yearly, for the initial pre-operational and first five yearly operational phase of the project.

8. MANAGEMENT MEASURES, ENVIRONMENT PERFORMANCE STANDARDS AND MEASUREMENT CRITERIA

8.1 Drilling and Completions

Table 8-1 outlines the design features / management measures that will be applicable to MODUs operating within the Torosa or Brecknock fields and Project Support Vessels assisting drilling and completions.

Table 8-1 - Mitigation and management measures applicable to anthropogenic noise from drilling and completions activities

Source of Aspect	Design Features/Management Measures	Environment Performance Standards	Monitoring & Measurement criteria
Moored Mobile Offshore Drilling Unit (MODU) operating within the possible foraging BIA	**Avoidance** Operation of a MODU **will not** occur at times and locations where foraging by PBWs is likely to occur within the area potentially ensonified above cetacean behavioural response threshold.	Received levels of underwater noise from a MODU does not exceed 120 dB at times and locations where foraging by PBWs is likely to occur.	Pre-operational and operational scientific monitoring results define times/locations where foraging by PBWs is likely to occur. Three years of data must be obtained at each relevant location to which avoidance measures are being applied.
	Minimisation Any MODU drilling at Torosa or Brecknock must not use a dynamic positioning system other than when transiting to/from the drilling location and connecting/disconnecting from moorings, unless for safety or emergency purposes. Drilling is not to occur while DP systems are active.	When operating within the possible foraging BIA at times/locations where foraging is not likely to occur, received levels of underwater noise from a MODU while moored on station does not exceed 120 dB greater than 500m from the noise source.	In-field underwater noise verification performed within first year of drilling campaign verifies MODU noise during drilling, while moored on station, does not exceed 120dB beyond 500m from the MODU.
	Detection and Mitigation The MODU must implement a vessel specific Noise Mitigation Plan (NMP) in accordance with **Section 9.3,** including: • Measures to detect whales within a defined observation zone; and • Measures to cease underwater noise sources (use of DP for transit and mooring connection/disconnection drilling) if a whale is detected within the relevant shut-down zone.	Drilling within the possible foraging BIA will cease if a whale enters the defined MODU shut down zone. Drilling will not recommence until whale confirmed to have left the shut down zone, or 30 minutes since the last detection.	Records in place show MODU implemented detection and mitigation measures in accordance with MODU NMP.
Project Support Vessels supporting MODU activities within the possible foraging BIA	**Minimisation** At times where a PSV is required to be on standby to a MODU, if the vessel is not moored, the vessel will remain at least 1km from a moored MODU and conduct standby operations in an easterly direction form the MODU. The vessel will limit DP use to that required to maintain heading and safe distance unless support vessel is required to be closer to manage safety during specific activities (i.e. helicopter landings, personnel working over the side) or if required for SOLAS.	PSVs on standby from MODU operating at Torosa maintain a 1km buffer to MODU and limit DP use.	Records in place show PSV maintained 1km buffer to moored MODU and limited engine (or thruster) use.
	Detection and Mitigation The PSV must implement a vessel specific Noise Mitigation Plan (NMP) in accordance with **Section 9.3,** including: • Measures to detect whales; and • Measures to cease underwater noise sources (use of PSV DP for MODU resupply) if a whale is detected within the relevant shut-down zone.	DP vessel usage ceased when whale observed within defined shut down zone when safe to do so. Vessel did not approach to within 3km of MODU without observing for whales or when a whale was present in the defined exclusion zone.	Records in place show MODU PSV implemented detection and mitigation measures in accordance with MODU PSV NMP.

8.2 SURF and IFL Construction and Installation

Table 8-2 outlines the design features / management measures that will be applicable to the following activities:

- SURF installation - construction vessels and reel-lay vessel
- Inter-field spurline installation – rigid pipelay vessel
- Project support vessels – general support and supply vessels servicing SURF and IFL installation

Table 8-2 Mitigation and management measures applicable to anthropogenic noise from construction and support vessels

Source of Aspect	Design Features/Management Measures	Environment Performance Standards	Monitoring & Measurement criteria
Construction and Installation Vessels, including: • SURF installation – construction vessels and reel-lay vessel • Inter-field spurline installation - rigid pipelay vessel	**Avoidance** SURF and IFL Installation will not occur at times/locations where foraging by PBWs is likely to occur. The spatial extent of this restriction will extend to any location 5km of the planned activity in which foraging has been identified as being likely to occur.	Received levels of underwater noise from SURF or FIL Construction and Installation Vessels does not exceed 120 dB at times and locations where foraging by PBWs is likely to occur.	Pre-operational and operational scientific monitoring results define times/locations where foraging by PBWs is likely to occur. Three years of data must be obtained at each relevant location to which avoidance measures are being applied. Vessel records show SURF and IFL Construction and Installation Vessels (including support vessels) complied with avoidance periods.
	Minimisation Contractors operating (or proposing to operate) construction vessels within the Possible Foraging Area will be required to identify specific measures that are available or will be in place to reduce noise. These are to be included in a noise mitigation assessment report.	When operating within the possible foraging BIA at times/locations where foraging is not likely to occur, received levels of underwater noise from a SURF Reel-Lay/Construction Vessel do not exceed 120 dB greater than 2.2km from the noise source.	Underwater noise characterisation report verifies Reel-lay vessel underwater noise estimates.*
		When operating within the possible foraging BIA at times/locations where foraging is not likely to occur, received levels of underwater noise from a Rigid Pipelay Vessel do not exceed 120 dB greater than 9.9km from the noise source.	Underwater noise characterisation report verifies Rigid Pipelay Vessel (including associated vessels) underwater noise estimates.*
	Detection and Mitigation All Construction and Installation Vessels must implement a vessel specific Noise Mitigation Plan (NMP) in accordance with **Section 9.3,** including: • Measures to detect whales; and • Measures to cease underwater noise sources (use of DP) if a whale is detected within the relevant shut-down zone.	Use of DP within the possible foraging BIA will cease if a whale enters the defined DP shut down zone. Use of DP will not recommence until whale confirmed to have left the shut down zone, or 30 minutes since the last detection.	Records in place show SURF and IFL Construction/Installation Vessels implemented detection and mitigation measures in accordance with Vessel NMP.
Project Support Vessels supplying Construction and Installation Vessels	**Minimisation** Contractors operating (or proposing to operate) construction vessels within the Possible Foraging Area will be required to identify specific measures that are available or will be in place to reduce noise. These are to be included in a noise mitigation assessment report.	PSV does not result in underwater noise ensonification of above 120dB at distances greater than 2.3km from the PSV.	Underwater noise characterisation report verifies PSV underwater noise estimates.* Noise Mitigation Assessment Report completed assessing feasibility of noise minimisation measures.
	Detection and Mitigation The PSV must implement a vessel specific Noise Mitigation Plan (NMP) in accordance with **Section 9.3,** including: • Measures to detect whales; and Measures to cease underwater noise sources (use of PSV DP for Construction vessel resupply) if a whale is detected within the relevant shut-down zone.	DP vessel usage ceased when whale observed within defined shut down zone when safe to do so. Vessel did not approach to within 3km of Rigid Pipelay Vessel without observing for whales or when a whale was present in the defined exclusion zone.	Records in place show PSVs implemented detection and mitigation measures in accordance with Vessel NMP.

**Note: In-Field Verification is not proposed for SURF/IFL Construction and Installation activities given they are short term activities within the Possible Foraging Area, and so the results of In-Field Verification cannot be used in a practical timeframe.*

8.3 FPSO Operations

Table 8-3 outlines the design features / management measures that will be applicable to the well heads within the Torosa field (including supporting vessel based activities)

Table 8-3 Mitigation and management measures applicable to anthropogenic noise from FPSO Operations

Source of Aspect	Design Features/Management Measures	Environment Performance Standards	Monitoring & Measurement criteria
Floating, Production, Storage and Offloading (FPSO)	**Minimisation** The Torosa FPSO will be designed to minimise the generation of noise during both normal operations and when using thrusters for heading control. An independent Classification Society will be engaged throughout the design process to verify that the Torosa FPSO thrusters and machinery are designed to achieve low noise targets.	Without the use of thrusters for heading control, FPSO noise at source will be 174 dB re 1µPa.m, and will not result in sound being received at >120dB at distances greater than 600m from the FPSO.	In-field underwater noise verification performed within first year of operations verifies FPSO noise without the use of thruster for heading control, does not exceed 120dB beyond 600m from the FPSO.
		With the use of thrusters for heading control, FPSO noise at source will be 178 dB re 1µPa.m, and will not result in sound being received at >120dB at distances greater than 1.7km from the FPSO (at thruster use limit).	In-field underwater noise verification performed within first year of operations verifies FPSO noise without the use of thruster for heading control, does not exceed 120dB beyond 1.7km from the FPSO. Torosa FPSO thruster use limit is integrated into FPSO control system to maintain noise below 178 dB re 1µPa.m.
	Detection and Mitigation The FPSO must implement a vessel specific Noise Mitigation Plan (NMP) in accordance with **Section 9.3,** including: • Measures to detect whales; and • Measures to cease the use of thrusters for heading control if a whale is detected within the relevant shut-down zone.	Use of thrusters for heading control within the possible foraging BIA will cease if a whale enters the defined FPSO thruster shut down zone. Use of thrusters will not recommence until whale confirmed to have left the shut down zone, or 30 minutes since the last detection.	Records in place show FPSO implemented detection and mitigation measures in accordance with FPSO NMP.
Offshore Support Vessels supplying FPSO or conducting Offtake	**Minimisation** Supply vessel operations supporting the Torosa FPSO shall be minimised as far as practicable during times when blue whale foraging is likely to occur and will not occur concurrently with condensate offtake operations.	During resupply, received levels of underwater noise from the offtake arrangement does not exceed 120 dB greater than 2.5km from the noise source.	Records in place show supply vessel operations minimised as far as practicable during times when blue whale foraging is likely to occur.
		During offtake, received levels of underwater noise from the offtake arrangement does not exceed 120 dB greater than 2.7km from the noise source.	Records in place show FPSO OSV resupply did not occur concurrently with offtake operations.
	Detection and Mitigation The OSV must implement a vessel specific Noise Mitigation Plan (NMP) in accordance with **Section 9.3,** including: • Measures to detect whales; and • Measures to cease underwater noise sources (use of PSV DP for MODU resupply) if a whale is detected within the relevant shut-down zone.	DP vessel usage ceased when whale observed within defined shut down zone when safe to do so. Vessel did not approach to within 3km of FPSO without observing for whales or when a whale was present in the defined exclusion zone.	Records in place show FPSO OSV implemented detection and mitigation measures in accordance with FPSO OSV NMP.

8.4 Wellhead Operations

Table 8-3 outlines the design features / management measures that will be applicable to the Well head Choke Valves (including supporting vessel based activities)

Table 8-4 Mitigation and management measures applicable to anthropogenic noise from well head choke valves

Source of Aspect	Design Features/Management Measures	Environment Performance Standards	Monitoring & Measurement criteria
Torosa Well Head Choke Valve Noise	**Minimisation** All well head choke valves to be installed within the Torosa field will incorporate measures to reduce noise from choke valves to achieve the underwater noise target (161.5 dB re 1 μPa·m) for all operational (flow rate, differential pressure) conditions.	Well head does not result in underwater noise ensonification of above 120dB at distances greater than 150m from the Well head.	Design verification performed on final wellhead design under expected conditions.

8.5 Impulsive Activities – Impact Piling & Vertical Seismic Profiling

Table 8-5 outlines the design features / management measures that will be applicable to the following activities:

- Vertical seismic profiling (Section 5.2.2)
- Impact piling (Section 5.2.1)

Table 8-5 Mitigation and management measures applicable to anthropogenic noise from impact piling and vertical seismic profiling

Source of Aspect	Design Features/Management Measures	Environment Performance Standards	Monitoring & Measurement criteria
Vertical Seismic Profiling	**Avoidance** VSP will not occur within the Scott Reef possible foraging area during peak PBW migratory periods. The spatial extent of this restriction will extend to any location 5km of the planned activity in which foraging has been identified as being likely to occur.	VSP does not cause injury to a pygmy blue whale.	Scientific monitoring program implemented to maintain contemporary definition of migratory periods.
	Minimisation *No mitigation measure proposed – use of VSP to evaluate hydrocarbon reservoirs is inherently minimizing the underwater noise source as it is a lower-noise alternative to 3D/4D seismic surveys.* *Seismic surveys are not within scope of referred activities subject to this plan.*	*N/A*	*N/A*
	Detection and Mitigation The VSP Vessel must implement a vessel specific Noise Mitigation Plan (NMP) in accordance with **Section 9.3,** including: • Measures to detect whales; and • Measures to cease underwater noise sources (use of VSP) if a whale is detected within the relevant shut-down zone.	VSP does not cause injury to a pygmy blue whale.	Records in place show VSP implemented detection and mitigation measures in accordance with VSP NMP.
Impact Piling	**Avoidance** Impact Piling will not occur within the Scott Reef possible foraging area during peak or shoulder PBW migratory periods.	Impact Piling does not cause injury to a pygmy blue whale.	Scientific monitoring program implemented to maintain contemporary definition of migratory periods.
	Minimisation Impact Piling will only be used if other forms of pile installation (including suction piling) are demonstrated not to be feasible.	Alternative form of pile installation selected and implemented, if feasible.	Piling installations uses alternative forms, unless geotechnical studies demonstrate alternative forms of piling are infeasible.
	Detection and Mitigation The Impact Piling Vessel must implement an activity specific Noise Mitigation Plan (NMP) in accordance with **Section 9.3,** including: • Measures to detect whales; and • Measures to cease underwater noise sources (Impact Piling) if a whale is detected within the relevant shut-down zone.	Impact piling does not cause injury to a pygmy blue whale.	Records in place show Impact Piling implemented detection and mitigation measures in accordance with Impact Piling NMP.

8.6 Alternative assessment

The following noise reduction mitigations were considered but not implemented.

8.6.1 Relocation of the Torosa FPSO to outside the Scott Reef possible foraging area

Given that Torosa FPSO represents a continuous noise source above 120 dB re 1 µPa, in line with the hierarchy of controls outlined in **Section 0**, consideration has been given to whether the FPSO could be located to where noise would not propagate to within the possible foraging area (i.e. approximately 20 km further east of its current location). An initial justification for the selected location of the Torosa FPSO was provided in the draft EIS/ERD.

Noting the priority given to controls higher up the hierarchy of controls, the environmental impact reduction benefit associated with eliminating the FPSO noise within the possible foraging area is considered to be limited as:

- The key scenarios where underwater noise is generated from the FPSO (i.e. using thrusters) can be managed using Whale Management Plans to reduce the likelihood of disrupting a pygmy blue whale while foraging;
- Unmitigable noise from the FPSO during normal operations ensonifies a very small percentage of the possible foraging area (~0.01%). This small ensonified area does not affect the Scott Reef channel or other locations within the BIA thought to support foraging activity.
- There is inherent uncertainty regarding possible pygmy blue whale foraging behaviour in the possible foraging area therefore moving the FPSO outside of the possible foraging area may not result in any reduction of potential impacts to foraging homogenous nature of the FPSO location and an arbitrary location beyond the BIA boundary, particularly if overall underwater noise increases when the FPSO is moved, as would be likely due to the need for increased thruster use (discussed further below).

Noting the environmental impact reduction benefit is considered to be negligible, there are a number of key risks and impacts introduced by a change in FPSO location:

a. **Torosa project infeasible due to lost production due to increased pressure drop.** Pressure management is critical to producing hydrocarbons. Hydrocarbons from the reservoir are conveyed from the reservoir to the FPSO facility under pressure from the reservoir (i.e. without subsea compression), and the hydrocarbon pressure drops along the flowline conveying the hydrocarbons from the reservoir to the facility, with the pressure drop increasing as the flowline length increases. The flowline lengths in the FPSOs current position already reduce the pressure by around 200 bar, from an expected reservoir pressure of 300-350 bar.

   Substantially increasing the flowline lengths will substantially increase the pressure drop, and will significantly reduce the overall amount of hydrocarbons that can be viably produced. The impact of increased pressure drop will be exacerbated as the reservoir pressure drops and will further reduce flowline capacity during the depletion compression phase. Adding additional compression may be required but is not considered further, as this would have higher impacts than the FPSO facility equipment. Further, other challenges associated with hydrate and wax management may increase the minimum flow rate that the subsea system can operate at, further reducing the hydrocarbon reserves that can be extracted.

b. **Increased use of thrusters from metocean conditions.** The key drive of the design case for FPSO thrusters is typically the management of a predominant swell from the south-west direction within the North-west Marine Region. However, the metocean conditions at the Torosa FPSO location have been measured to be relatively benign due to the sheltering effect of Scott Reef from the south-west swell. An analysis of 40-year hindcast Metocean information shows increasing average (P50) significant wave height (Hs – a representation of sea state), which correlates with increasing thruster use the further away from Scott Reef the FPSO is moved (refer **Figure 8-1**).

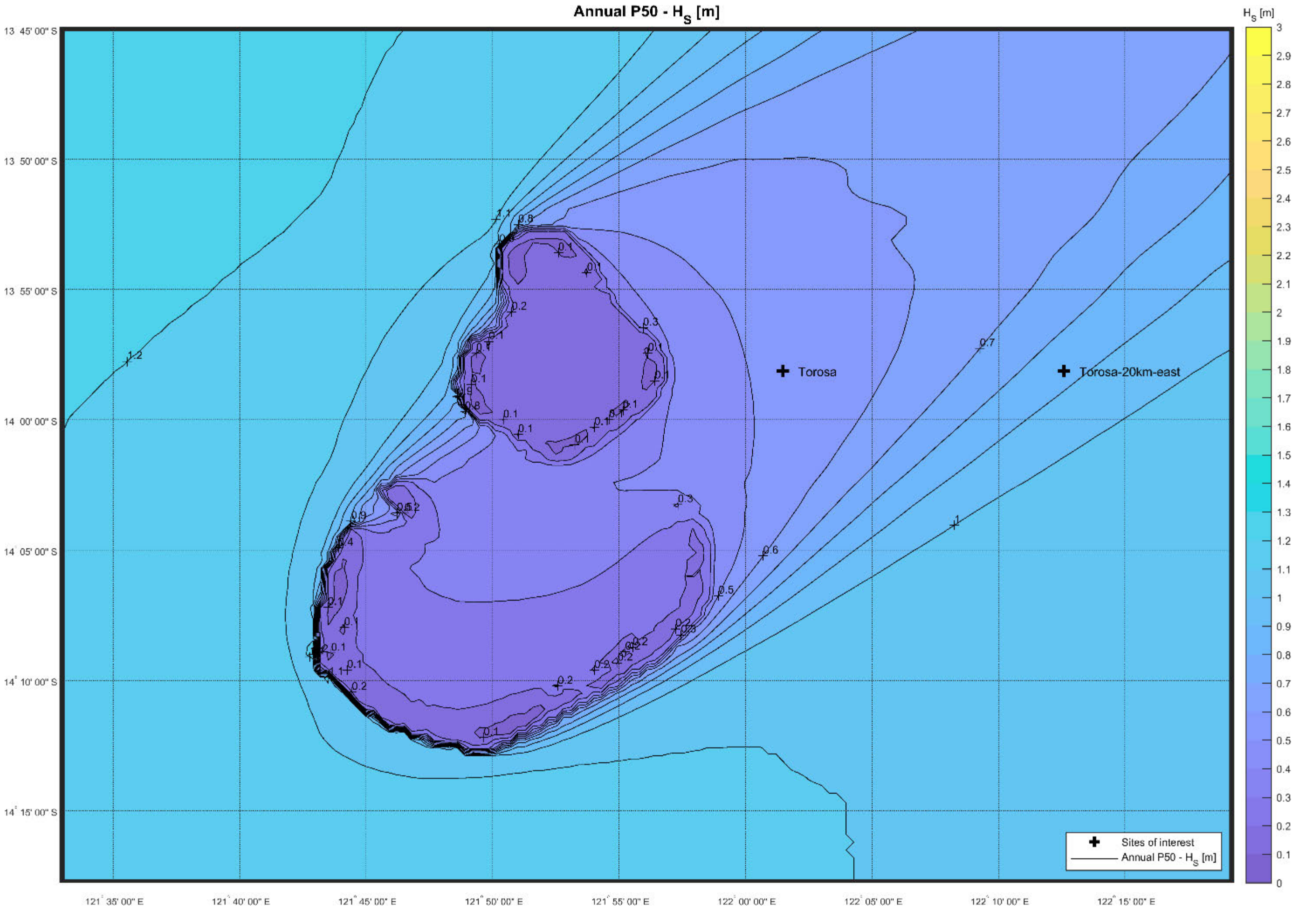

Figure 8-1. Sheltering Effect of Scott Reef on Mean (P50) Significant Wave Height (Hs)

Moving the FPSO approximately 20 km east (necessary to eliminate noise associated with activities such as offtake from ensonifying the Scott Reef possible foraging area above 120 dB re 1 μPa), or even further to the north-east, would increase the risk of more frequent and substantial use of the FPSO thrusters, and therefore the level of overall underwater noise being generated.

c. **Feasibility of Active Heating.** The proposed Browse Project is proposing to use active heating of the flowlines as the technology for managing the risk of hydrate formation and blockage in the subsea system, with the active heating only required during shut-down and start-up operations. As described in Chapter 7 of the draft EIS/ERD, active heating is a substantial energy efficiency improvement, as the alternative requires continuous MEG dosing and a highly energy intensive MEG regeneration plant on the facility.

Increasing the flowline lengths would increase the technical risks and commercial costs associated with active heating. At this stage it is currently not known if it is economically viable to supply active heating over this distance, particularly given current limitations on the amount of power that can be transmitted through the FPSO Swivel System. If a MEG regeneration plant were to be used in place of the active heating technology, this would potentially increase Torosa facility CO_2 emissions by 100,000 tonnes per year.

d. **Installation Risks.** With the current FPSO location, a flowline can be installed from a single continuous reel lay activity. If the flowline lengths increase, a flowline will need to be installed in two parts on the sea bed, with a significantly more complex activity to pick up and weld the flowlines together. Note that the flowline infrastructure is substantially more complex than the Browse Trunkline, in that the flowline integrates a number of services including: the pipe-in-pipe fitted with insulation, two optical fibre cables and up to 12 active heating electrical cables in the annulus between the inner and outer pipe. Unlike the BTL (where welds occur as pieces are laid from the vessel), this activity will require the lifting of the previously installed flowlines from the seabed in order to perform the welding of the inner and outer pipes as well as splicing of all optical fibre and active heating electrical cables. Given the complexity of the flowline infrastructure, this substantially increases the risks of technical problems arising during installation.

Conclusion

Further to the above key impacts, additional materials and subsea disturbance would increase the overall environmental impact with a decision to move the FPSO outside of the Scott Reef possible foraging area, while providing negligible environmental benefit. Based on the above key risks, moving the FPSO further away from the Torosa reservoir would challenge the viability of developing the Torosa field.

8.6.2 Elimination of Drilling and Completion activities at the Torosa and Brecknock fields during Peak periods of the Pygmy Blue Whale Migratory Seasons

Consideration has been given to whether drilling and completion activities could be eliminated at the Torosa and Brecknock fields during pygmy blue whale migratory seasons. There are two possibilities that would achieve this:

1. Relocate the drill centres to outside of the Scott Reef possible foraging area

The current location of the proposed drill centres is designed to optimise access to hydrocarbon reserves across the Torosa field. Based on current and expected technology, there is a maximum distance that wells can be drilled to effectively recover hydrocarbons. Relocating the drill centres to outside of the Scott Reef possible foraging area would not allow access to the majority of the hydrocarbons at Torosa, and would not allow for a viable development.

2. Avoid drilling and completion activities during peak periods of the pygmy blue whale migratory seasons

Eliminating drilling and completion activities during the peak periods of the pygmy blue whale migratory seasons would result in the inability to drill during three non-consecutive months of the year (May, June and November) based on current understanding. As per the management measures provided in **Section 8**, a MODU at Torosa will not use a dynamic positioning system to hold station during drilling. In order to achieve this management measure, a MODU with conventional mooring capability may be selected by the Project (or DP MODU with substantially lower than typical noise).

If the proposed Browse Project does select a conventionally moored MODU, then it may not be possible to conduct drilling and completions activities during cyclone season. The combination of not being able to drill in cyclone season and not being able to drill during peak periods of the pygmy blue whale migratory seasons results in substantial impacts on the available time of the year where drilling and completion activities are acceptable, with the longest time period being three months from August-October. As it takes up to approximately three months to drill and complete each well, this schedule would not be viable to provide wells ready for Torosa FPSO RFSU, or for any future phases.

9. NOISE MITIGATION PLANS

9.1 Overview

Noise Mitigation Plans (NMPs) are operational procedures that will be applicable to a range of activities during execution of the proposed Browse Project. The NMPs will outline the mitigations that must be applied in relation to monitoring for and responding to sightings of pygmy blue whales. The principles of the NMPs can also be applied at other locations where biologically important behaviours may occur (e.g., the migratory BIA). Activity specific NMPs will be developed as further details of the activity (i.e., timing, vessel type) are known, during the execution phase of the proposed Browse Project. The principles of the NMPs are outlined below – each relevant activity will have to apply these principles to develop a NMP specific to that activity.

As per **Section 8**, the following activities must have a NMP in place prior to field work commencing:

- All vessels operating in the Scott Reef possible foraging area (including construction, support/supply vessels, MODUs and the Torosa FPSO) and any construction vessel operating within 9 km of the possible foraging BIA (**Section 9.3**)
- Impact piling activities (**Section 9.3.2**)
- VSP activities (**Section 9.3.3**).

The purpose of the NMPs is to ensure that appropriate mitigation measures are implemented to reduce the risk of displacement of pygmy blue whales from foraging occurring where modelling has indicated that behavioural disturbance within the possible foraging area may occur. Plans are modelled on recent precedent conditions established for comparable activities in locations of similar environmental sensitivity.

The key elements of the NMPs are outlined below and have been developed based on guidance with EPBC Act Policy Statement 2.1 procedure, Bröker (2019) and recently approved Environment Plans governing activities in high use foraging areas for the pygmy blue whales (e.g. Beach Energy 2021).

The intent of the NMPs for project vessels (continuous noise source) is not to manage the risk of injury to a whale, as TTS could not credibly occur as a result of these activities. For vessel based activities, distances to TTS thresholds are typically met within 400 m of an individual vessel (max 1.5 km for cumulative impact of multiple construction vessels). Therefore, as injury from exposure to vessel noise requires exposure for more than 24 hours, the risk of this occurring is not considered credible given the daily distances typically travelled by pygmy blue whales during migratory periods.

Impulsive noise activities present a different injury risk and are subject to their own management procedures which are designed to ensure that appropriate mitigation measures are implemented to reduce the risk of injury to pygmy blue whales as well as displacement of pygmy blue whales from the possible foraging area occurring during operations where modelling indicates that injury or behavioural disturbance within the possible foraging area may occur.

9.1 Principles of Noise Mitigation Plans

The following key principles must be incorporated into each NMP:

- Impact assessment - A description of the area that may be impacted by anthropogenic noise from the activity. This will inform the area in which response measures / mitigations will be applied.
- Monitoring – An overview of how/when monitoring for pygmy blue whales will be undertaken, including which techniques will be employed and a justification for non-standard techniques.
- Response measures - What actions will be taken if a pygmy blue whale is observed within or approaching monitoring/shutdown zones.

- Reporting – detailed records of observations and mitigative actions must be taken, including and non-conformances or corrective actions.

9.2 Pygmy Blue Whale Detection Techniques

Currently, the most common technique for detecting whales from vessels utilise visual observation techniques, either from a Marine Mammal Observer (MMO)[6] on board the source vessel or, from a plane/helicopter.

Marine Mammal Observers will be typically be used as the main Pygmy Blue Whale detection technique. Where an activity requires a dedicated MMO to be present, any MMO will be limited to a maximum two-hour continuous shift with a minimum of one hour as a break between shifts. The MMOs will be located on the bridge or at the highest elevation available on the source vessel(s) with the maximum viewable range from the bow to 90˚ port/starboard of the vessel. There will be a single-point authority for activity modification/shutdown triggered by whale observations, and this will lie with the on-shift Senior MMO.

Occasionally, this is supplemented by observational techniques such as PAM, infra-red or night vision. Within this plan, if there is a requirement to observe for whales and these observations rely on visual techniques, these observations must be performed during daylight hours with the corresponding activity not occurring in periods of low visibility, if visual observations are to be utilised. Alternative observation techniques can be applied if it can be validated as having an equal or greater accuracy of whale sighting as an MMO during daylight hours.

During construction of the wells, fibre optic cables with acoustic sensors will be installed in the wells and connected back to the FPSO. This system is called Distributed Acoustic Sensing (DAS) and will be operational once the FPSO is installed. DAS will be employed for the duration of Browse operations, and this data will be processed in near-real time and used to inform mitigation of noise generating activities and contribute to knowledge of regional whale presence.

9.3 Noise Mitigation Plan Contents

Noise Mitigation Plans for specific activities will not be able to be developed until the contracting process for individual vessels has commenced. It is anticipated that each vessel's Noise Mitigation Plan will be developed collaboratively with operational representatives from the vessel/activity.

To provide greater clarity on the contents of the Noise Mitigation Plans, a summary of the expected contents for each of the key activities has been provided below.

9.3.1 NMP Framework for Vessels

A Project Vessel NMP will describe the following:

- **Detection Controls:** The controls that the Project Vessel will put in place to effectively detect a nearby whale. Detection controls will be in accordance with **Section 9.2**.
- **Key Underwater Noise Sources:** The key underwater noise sources associated with the Project Vessel that will be ceased if a whale is detected in the relevant Shutdown Zone (see definition below), unless doing so would endanger human safety, the vessel or equipment. For most vessels, this is the dynamic positioning/propulsion system, but for the MODU this will include formation drilling. The underwater noise source level will be characterised for each key underwater noise source.
- **Residual Underwater Noise:** The residual underwater noise of the vessel without key noise sources will also be characterised.

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[6] Marine Mammal Observer – a dedicated and suitably trained person who must not have any other duties that impede their ability to engage in visual observations during the required observation period. They may have other duties on board the vessel at other times.

- **Arrival Requirements:** Prior to arrival at the activity location, if one or more blue whales are observed to be present in proximity to the activity location, then the vessel will not approach the activity location. This may involve the vessel remaining on standby at a safe distance until blue whales are no longer present. Once blue whales have not been detected within proximity of the activity location for 30 minutes, the relevant Project vessel may approach the activity location.
- **Monitoring Zone:** The zone within which Project Vessels will monitor for whales. If a whale is detected within this zone, the Project Vessel must prepare to cease key underwater noise sources, unless doing so would endanger human safety, the vessel, or equipment. The Monitoring Zone size must be at least 0.5km larger than the Shutdown Zone.
- **Shutdown Zone:** The zone within which Project Vessels must cease key underwater noise sources, unless doing so would endanger human safety, the vessel or equipment. This Shutdown Zone size is equal to the distance from the vessel to the cetacean behavioural response threshold, as determined by modelling.
- **Residual Noise Zone:** The zone within which a whale may be exposed to underwater noise above the behavioural response threshold from residual vessel noise, once key underwater noise sources have been ceased. Note that this noise zone is very small for most vessels <0.5km).
- **Pre-start Requirements:** The requirements that must be implemented prior to the commencement of key underwater noise sources. Prior to commencement, observations must be made of the Monitoring Zone for a continuous period of 30 minutes. Key underwater noise sources can only be commenced if no whales have been detected within the Monitoring Zone for 30 minutes.
- **Restart Requirements:** The requirements that must be implemented prior to the recommencement of key underwater noise sources post cessation. Prior to recommencement, observations must be made of the Monitoring Zone for a continuous period of 30 minutes. Key underwater noise sources can only be commenced if no whales have been detected within the Monitoring Zone for 30 minutes, or if the whales which caused the cessation have been observed leaving the Monitoring Zone.
- **Reporting Requirements:** The reporting requirements for whale observations by the vessel. This will include whether the whale entered the Monitoring, Shutdown or Residual Noise Zones, as well as any observations on whale behaviour (such as travelling speed and direction).
- **Assurance Requirements:** The process for routinely assuring that the NMP is being correctly implemented.
- **In-Field Verification Revision Requirements:** If required, the process for revising the NMP to account for the results of In-Field Verification as described in **Section 6.2.3.**

9.3.2 NMP Framework for Impact Piling

To mitigate the risk of injury to and/or displacement of blue whales from the possible foraging area as a result of impact piling activities:

- A 3000 m Monitoring Zone will be applied
- An Exclusion Zone will be implemented so as to ensure that whales are not exposed to Sound Exposure Levels of greater than or equal to 183 dB re 1 p Pa2.s. The Exclusion Zone will be no less than a 2000 m radius around the pile hammer.

If impact piling is to be utilised, then to minimise the impacts of noise to pygmy blue whales, the following measures will be implemented:

- Impact piling is not to occur within the Scott Reef channel.
- Avoidance period: No impact piling shall occur at times when pygmy blue whale foraging is likely to occur.
- Pre-start-up visual observations: Visual observations for pygmy blue whales must be undertaken to the extent of the Monitoring Zone for at least 30 minutes before the commencement of impact piling activities. Impact piling may not commence until the observations of the Monitoring Zone has confirmed pygmy blue whales are not present.
- Operating procedures: The following procedures will be implemented during operations:
  - Visual observations of the Monitoring Zone will be maintained continuously during impact piling to identify if any pygmy blue whales enter the Exclusion Zone.
  - If pygmy blue whales are sighted within the Exclusion Zone, action to suspend all impact piling within the Exclusion Zone will be taken within 2 minutes or as soon as safely possible.
  - Impact piling activities will not recommence until the pygmy blue whales are observed to move outside the Exclusion zone or 30 minutes have passed since the last sighting.
  - Soft ‘fairy taps’ start procedures: Impact piling activities will be initiated at the soft ‘fairy taps’ start level and then build up to full operating impact force. The soft ‘fairy taps’ start procedures will only commence if no pygmy blue whales have been sighted within the Exclusion Zone during the pre-start-up visual observations.

9.3.3 NMP Framework for Vertical Seismic Profiling (VSP)

To minimise impacts to whales, Part A ‘Standard Management Procedures’ of the EPBC Act Policy Statement 2.1 - Interaction between offshore seismic exploration and whales (Seismic Guidelines) will be implemented during all VSP operations, using a 1000 m Monitoring Zone, 500 m Exclusion Zone and a 1,000 m Low Power Zone.

The 1000 m low power zone will be used where it can be demonstrated that the received sound exposure level for each shot will not exceed 160 dB re 1Pa2s, for 95% of acoustic shots at 1000 m range.

In addition, the following management measures will be implemented during all Vertical Seismic Profiling (VSP) operations:

- **Avoidance period:** VSP will not occur at times/locations where foraging by PBWs is likely to occur. The spatial extent of this restriction will extend to any location 5km of the planned activity in which foraging has been identified as being likely to occur.
- **Pre-start-up visual observations**: Visual observations for pygmy blue whales must be undertaken to the extent of the Monitoring Zone for at least 30 minutes before the commencement of VSP activities. VSP may not commence until the observations of the Monitoring Zone has confirmed pygmy blue whales are not present.
- **Operating procedures**: The following procedures will be implemented during operations:
  - Observations of the Monitoring Zone will be maintained continuously during VSP to identify if any pygmy blue whales enter the Exclusion Zone.
  - If pygmy blue whales are sighted within the Exclusion Zone, action to suspend all VSP within the Exclusion Zone will be taken within 2 minutes or as soon as safely possible.
  - VSP activities will not recommence until the pygmy blue whales are observed to move outside the Exclusion zone or 30 minutes have passed since the last sighting.

10. RESIDUAL UNDERWATER NOISE

To inform a cumulative impact assessment, the following section presents an overview of the residual underwater noise expected to overlap with the Scott Reef possible foraging area after application of the management framework outlined in this plan.

To provide estimates of cumulative impacts that might better inform management measures to be applied within this plan, the following provides a quantitative description of cumulative underwater noise in the Scott Reef possible foraging area during key stages of the proposed Browse Project. The analysis presented in this section accounts for design features and management measures that have been outlined in **Section 8**, and provides a distinction between ensonified areas in the wider Scott Reef possible foraging area and the Scott Reef channel (further discussed in **Section 5.3**).

To provide aid interpretation, the spatial extent of the ensonified areas described in each of the key phases of the activities are shown visually using simplified noise field maps.

10.1 Drilling and Completions (Phase one – Pre RFSU)

Prior to the initial construction and installation of subsea and FPSO facilities at the Torosa field, a MODU is expected to be present, drilling across a period of two to three years.

Table 10-1 shows the key drilling and completions underwater noise sources once management measures have been applied in accordance with **Section 8.**

Figure 10-1 illustrates notionally the underwater noise ensonified areas (above 120 dB) associated with the MODU alone and during resupply, during phase one drilling.

Table 10-1 Characteristics and Residual Underwater Noise of Drilling and Completions Noise Sources

Underwater Noise Generating Activity	Seasonal avoidance measures feasible?	Noise can be ceased under NMP?	Sound Source Level (dB re 1 µPa·m)	R_{max} (km)	Ensonified Area (km^2)	Percentage of Possible Foraging Area
MODU moored while drilling	Yes	Yes	171	0.49	0.8	0.006%
Moored MODU OSV Resupply	Yes	Yes	182	2.3	16.6	0.1%
MODU while transiting to site	Yes	Yes	183	4.5	63.6	0.5%
MODU (Residual)	Yes	No	163	0.2	0.1	**0.001%**

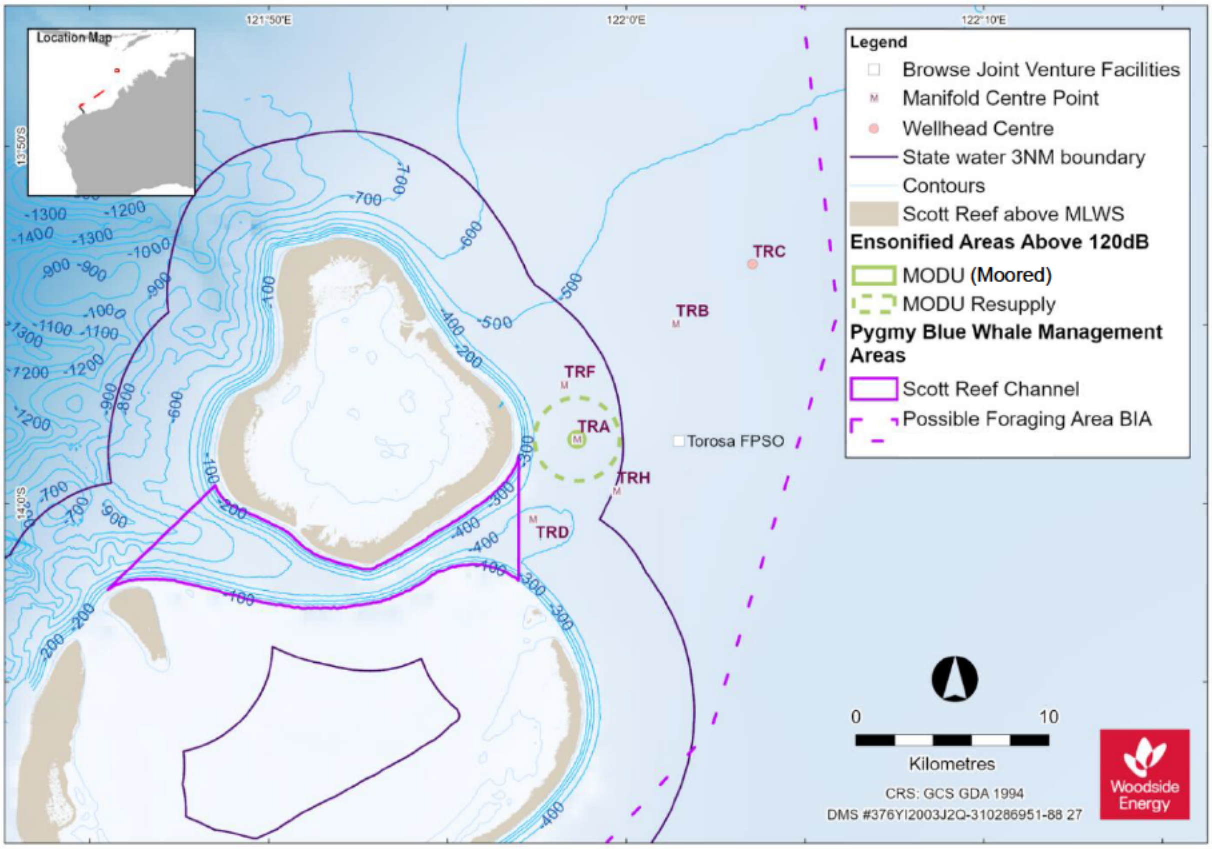

Figure 10-1 Illustrative peak cumulative ensonified areas (above 120 dB) during Phase One Drilling and Completions. Drilling at TRA shown as a representative scenario. This activity will not occur during times when blue whale foraging is likely to occur.

As a result of the applied mitigations, residual continuous underwater noise generation (outside of times important to PBW foraging) above behavioural response thresholds is limited to ~0.6km from the MODU which can be further reduced to ~0.2km from the MODU upon detecting a whale and ceasing drilling (as managed by NMP), with short periods of increased noise generation (2.3km from the MODU) associated with operational support vessel supply or MODU transit, both of which can be ceased if a PBW is detected.

Given that the MODU will not be present at times and locations when and where blue whale foraging is likely, and that in-field adaptive management reduces the ensonified area (above behavioural response thresholds) to ~0.2km, the risk that an individual foraging blue whale which approaches to within very close proximity around the MODU would then be disturbed by the MODU is remote. Given the very small ensonified area, there is a high confidence that disturbance would not cause the whale's broader utilisation of the Foraging Area to be impacted and therefore would not cause biologically significant behavioural disturbance or reduced population fitness.

10.2 Subsea and FPSO Construction and Installation (pre-RFSU)

The initial (pre-RFSU) construction and installation of subsea and FPSO facilities at the Torosa field location extends for approximately two years, during which time the drilling and completion activities of Phase 1 wells will be ongoing. As outlined in **Section 5.1**, each of the key activities in the construction sequence (spur-line installation, subsea installation and FPSO hookup) are consecutive, not concurrent. Therefore, it is not anticipated that these activities will co-occur and therefore they are not anticipated to contribute spatially to cumulative underwater noise.

Table 10-2 shows the key subsea and FPSO Construction and Installation underwater noise sources once management measures have been applied in accordance with **Section 8**. **Figure 10-2**, **Figure 10-3** and **Figure 10-4** illustrates the underwater noise ensonified areas (above 120 dB) associated with Reel Lay, Rigid Pipelay of the Inter-Field Spur Line and FPSO Mooring and Subsea Hookup, respectively.

Table 10-2 Characteristics and Residual Underwater Noise of Subsea and FPSO Construction Sources

Underwater Noise Generating Activity	Seasonal avoidance measures feasible?	Noise can be ceased under NMP?	Sound Source Level (dB re 1 µPa·m)	R_{max} (km)	Ensonified Area (km^2)	Percentage of Possible Foraging Area (%)
Offshore installation or flexible reel-lay vessel	Yes	Yes	181	2.2	15	0.1%
Rigid Pipelay Vessel, with attendant PSVs	Yes	Yes	191	9.9	107	0.9%
FPSO Mooring and Subsea Hookup (approx. 4 vessels)	No	Yes	184 (per vessel)	2.44	19	0.2%

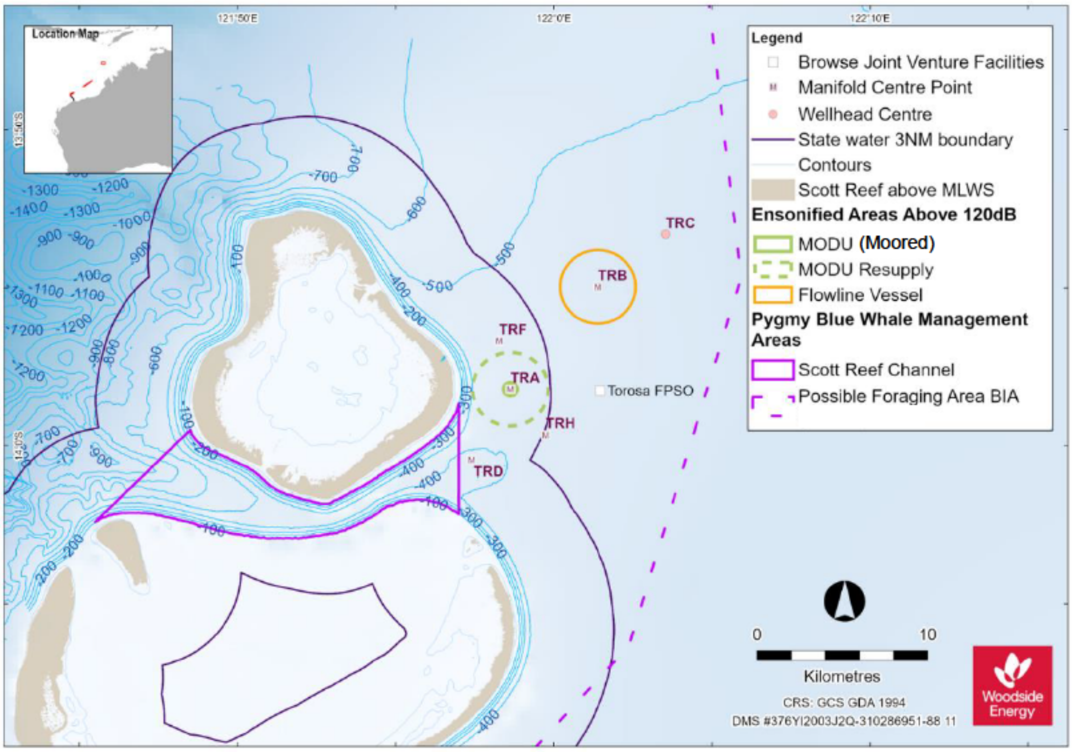

Figure 10-2 Illustrative peak cumulative ensonified areas (above 120dB) during subsea installation i.e. flowline reel-lay (Pre-RFSU). Scenario shows a moored MODU drilling at TRA concurrent with reel-lay at TRB. Ensonification does not occur during times when blue whale foraging is likely to occur.

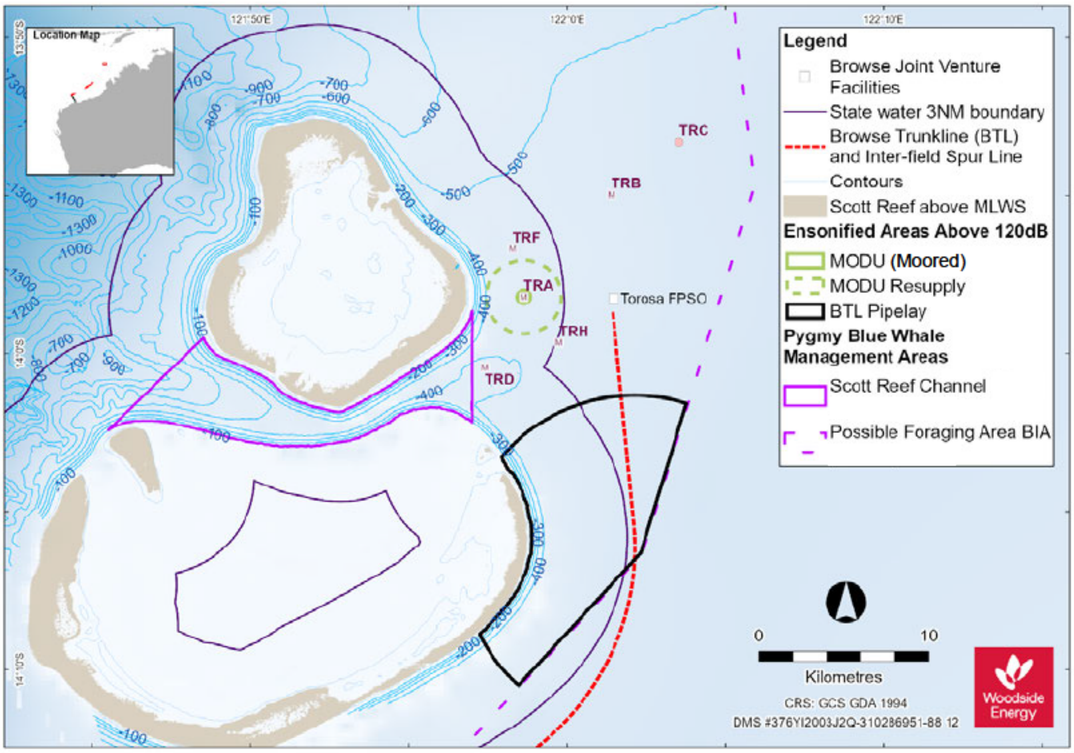

Figure 10-3 Illustrative peak cumulative ensonified areas (above 120dB) during Inter-Field Spur Line Installation, at the limits of the possible foraging area. Scenario shows a concurrent moored MODU drilling at TRA. Ensonification does not occur during times when blue whale foraging is likely to occur.

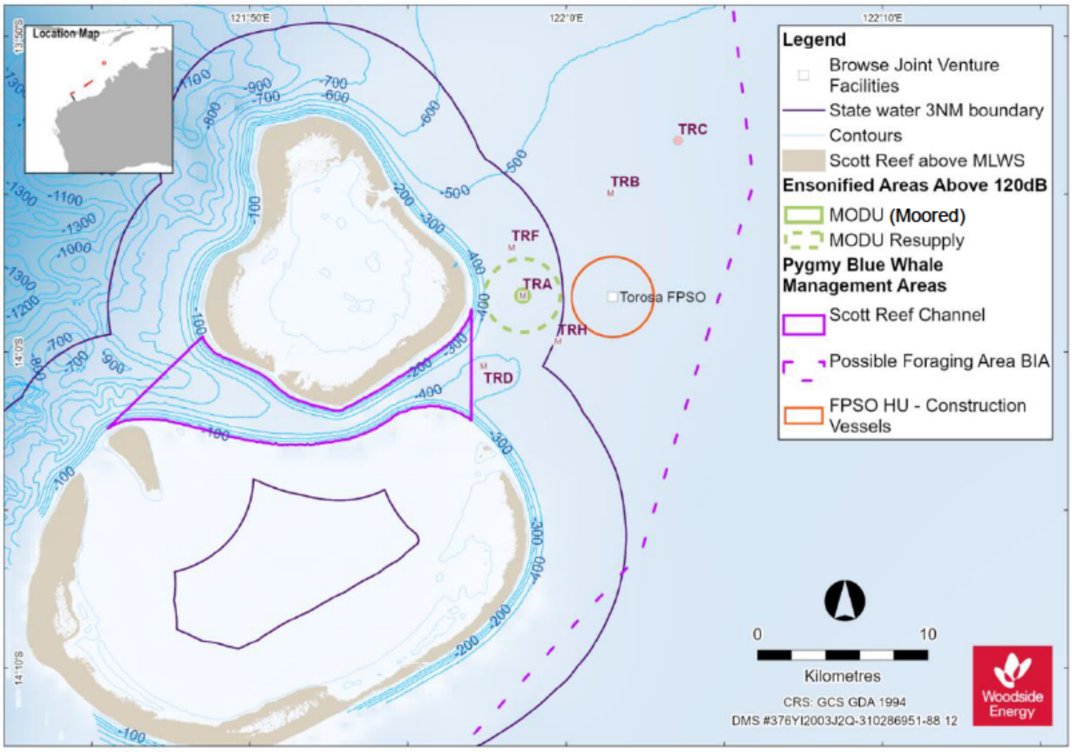

Figure 10-4 Illustrative peak cumulative ensonified areas (above 120dB) during FPSO hook up (Pre-RFSU). Scenario shows a moored MODU drilling at TRA concurrent with the installation of the Torosa FPSO.

As a result of the applied mitigations, residual continuous underwater noise generation (outside of times important to PBW foraging) above behavioural response thresholds less than 1% of the possible foraging area.

IFL Installation and FPSO Installation and Hook-Up are both one-off activities that do not occur at the same time. IFL Installation is anticipated to require only 2 weeks in the Possible Foraging Area, and FPSO Hookup is anticipated to require only six weeks with 4 vessels, after which a smaller number of vessels are required.

Subsea installation is anticipated to require only one to two months of vessel time for each of the three drill centres in the Proposal area. Installation at each drill centre is anticipated to be phased years apart.

Given that subsea installation activities will not occur at times and locations when and where PBW foraging is likely, that subsea and FPSO installation activities are short duration, and that in-field adaptive management will reduce the ensonified area by turning off dynamic positioning (unless cessation would endanger human safety, the vessel or equipment), the risk that an individual foraging PBW which approaches to within very close proximity around the vessel would be disturbed by the vessel is remote. Given the very small ensonified area, there is a high confidence that disturbance would not cause the whale's broader utilisation of the foraging area to be impacted and therefore would not cause biologically significant behavioural disturbance.

10.3 FPSO Operations

The FPSO is on a permanently moored facility and is on station for the operational life of the Project (expected 30 years). The FPSO is routinely supported by an OSV for resupply, and requires an offtake activity approximately every 2-4 weeks. The OSV providing resupply and OSV offtake support (static tow) operations are anticipated to be the same vessel, specifically hired for Project activities.

Table 10-3 shows the key FPSO underwater noise sources once management measures have been applied in accordance with **Section** Error! Reference source not found.**.**

Figure 10-5, **Figure 10-6** illustrates the underwater noise ensonified areas (above 120 dB) associated with the FPSO OSV resupply and FPSO Offtake, respectively.

Table 10-3 Characteristics and Residual Underwater Noise of FPSO Operations Noise Sources

Underwater Noise Generating Activity	Seasonal avoidance measures feasible?	Noise can be ceased under NMP?	Sound Source Level (dB re 1 µPa·m)	R_{max} (km)	Ensonified Area (km^2)	Percentage of Possible Foraging Area (%)
FPSO using thrusters for heading control	No	Yes	178	1.7	9.1	0.1%
FPSO OSV resupply (no FPSO thrusters)	No	Yes	182	2.3	16.6	0.1%
FPSO OSV resupply with thrusters	No	Yes	185	2.5	19.6	0.2%
FPSO (Residual)	No	No	174	0.6	1.1	0.01%
FPSO Offtake (24 hours every 2-4 weeks)	No	No	186	2.7	22.9	0.2%

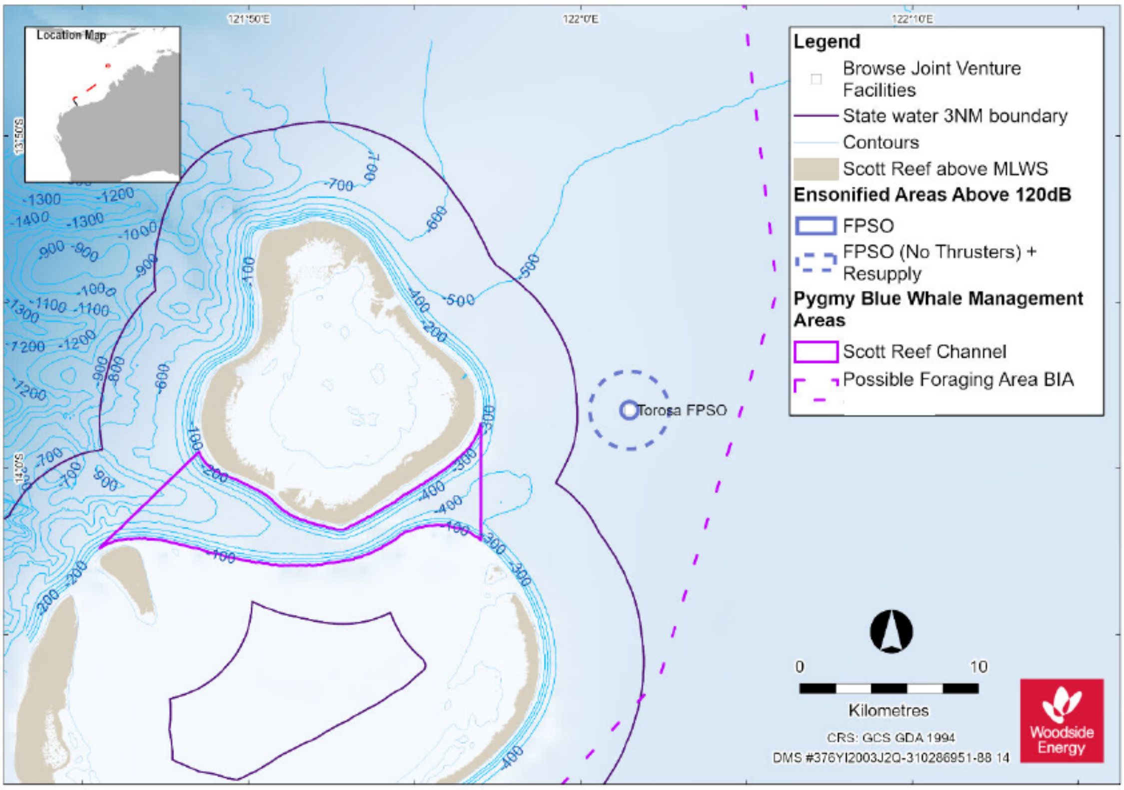

Figure 10-5 Illustrative peak cumulative ensonified areas during normal operation of the Torosa, FPSO showing typical operation of the Torosa FPSO (no thrusters, solid blue line) and re-supply with FPSO thrusters off (dashed line).

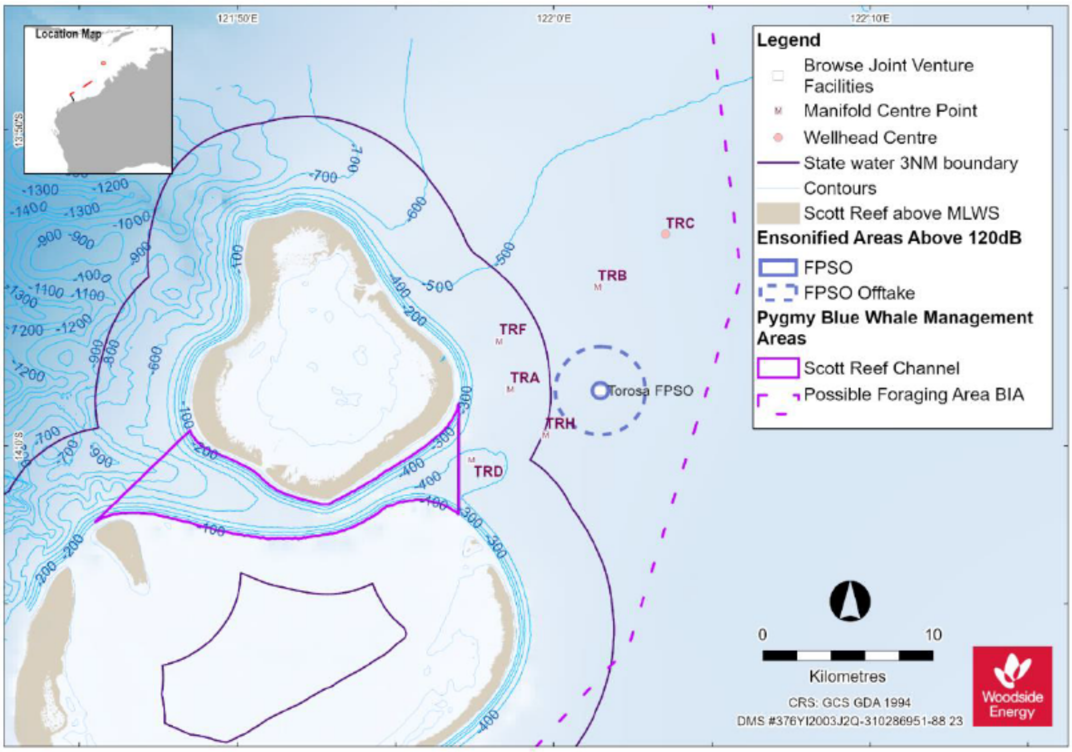

Figure 10-6 Illustrative, peak cumulative ensonified areas during normal operation of Torosa, showing condensate offtake from the Torosa FPSO (dashed line). Subsea well head noise does not reach the surface at relevant thresholds.

As a result of the applied mitigations, residual underwater noise generated by the FPSO ensonifies up to 1.7km away from the FPSO, which can be reduced to ~0.6km upon detecting a whale and ceasing OSV resupply or use of FPSO thrusters (as managed by NMP).

In addition, there will be short periods of increased noise generation (2.5km from the FPSO) when an OSV resupply is happening, which can also be reduced to 0.6km (as managed by NMP). Condensate Offtake support, which results in increased noise generation (2.7km from the FPSO), cannot be ceased upon detecting a whale, as OSV thrust is required to maintain integrity of the operation.

Given that the FPSO in-field adaptive management reduces the ensonified area (above behavioural response thresholds) to 0.6km, the risk that an individual foraging blue whale which approaches to within very close proximity around the FPSO would then be disturbed by FPSOMODU is remote. Given the very small ensonified area, there is a high confidence that disturbance would not cause the whale's broader utilisation of the Foraging Area to be impacted and therefore would not cause biologically significant behavioural disturbance or reduced population fitness.

10.4 Wellhead Operations

Underwater noise associated with choke valve (well head) noise originates from the seabed (~ 350-500 m deep) as opposed to the sea surface (as is the case for vessels). Choke valves will be operating for the full field life of the Project.

Table 10-4 shows the key FPSO underwater noise sources once management measures have been applied in accordance with **Section 8**. **Figure 10-7** illustrates the underwater noise ensonified areas (above 120 dB) associated with the Subsea well heads – note unlike other figures in this section, underwater noise is presented at seabed, not surface.

Table 10-4 Characteristics and Residual Underwater Noise of Wellhead Operations Noise Sources

Underwater Noise Generating Activity	Seasonal avoidance measures feasible?	Noise can be ceased under NMP?	Sound Source Level (dB re 1 µPa·m)	R_{max} (km)	Ensonified Area (km^2)	Percentage of Possible Foraging Area (%)
Well Heads (Residual)	No	No	161.5	0.36	2.4	0.02%

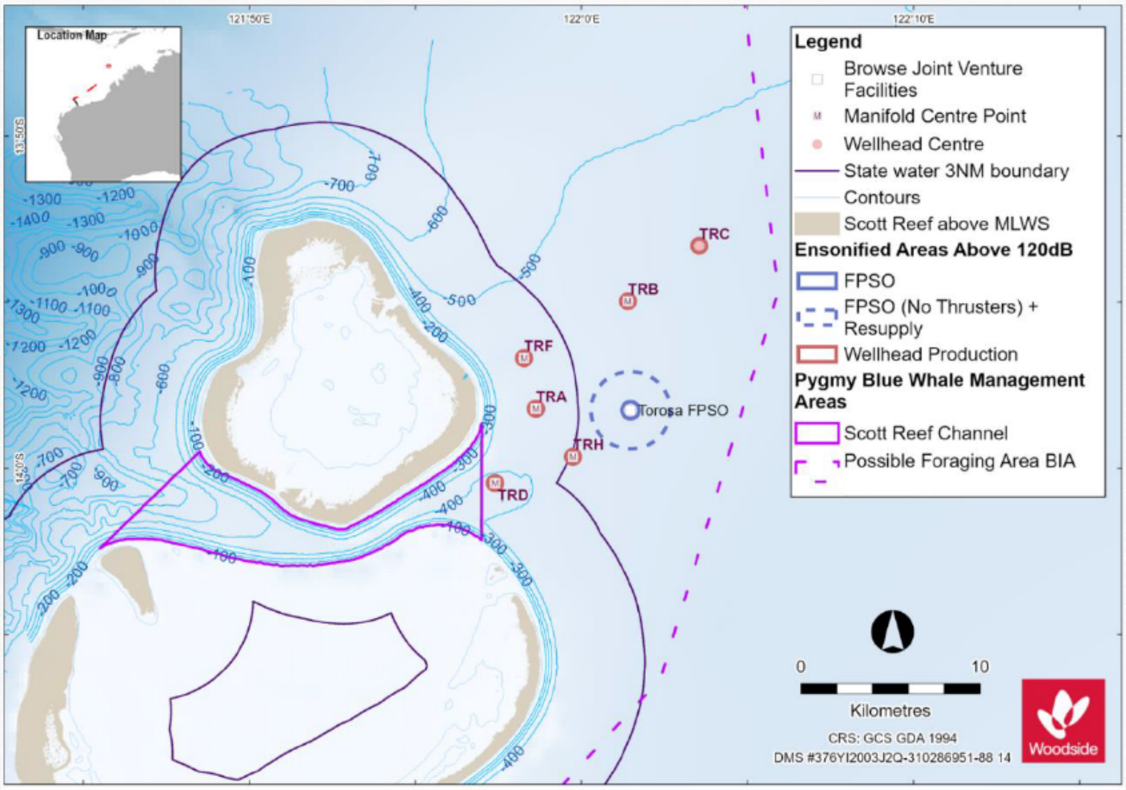

Figure 10-7 Illustrative, peak cumulative ensonified areas during normal operation of Torosa Well Heads, showing underwater noise at sea bed only. Subsea well head noise does not reach the surface at relevant thresholds.

As a result of the applied mitigations, residual continuous underwater noise generation above behavioural response thresholds is expected to be limited to ~0.1km at seabed from each of the three drill centres. Underwater noise generation is not anticipated to exceed behavioural response thresholds in the upper 200m of the water column, where previous water quality monitoring studies indicate that primary productivity is occurring (Brinkman et al 2010).

While a PBW can dive beyond the upper 200m of the water column, it is highly unlikely that foraging opportunities are present in this region below 200m due to the absence of primary productivity at these depths. Given that design minimisations are anticipated to reduce the ensonified area (above behavioural response thresholds) to ~0.1km of the drill centre, the risk that an individual foraging PBW which approaches to within very close proximity around the drill centre would then be disturbed by a wellhead is remote. There is a high confidence that disturbance would not cause the whale's broader utilisation of the foraging area to be impacted and therefore would not cause biologically significant behavioural disturbance or reduced population fitness.

10.5 Subsequent Subsea Tie-back Phases

Subsea tie-back phases that will occur after the initial Torosa FPSO RFSU period are described in **Section 2.4**.

Future tie-back phases will apply the same mitigations for Drilling and Completions and SURF Construction and Installation found in **Section 8**, including seasonal avoidance measures and use of a moored MODU. During subsequent subsea tie-back phases, the key activities that may occur simultaneously include:

- a FPSO (solid blue line on **Figure 10-8**), which may include a condensate offtake or OSV resupply event (dashed blue line on **Figure 10-8**); and
    - a moored MODU, which may include OSV resupply (solid and dashed green lines on **Figure 10-8**), or
    - a reel-lay installation vessel or construction vessel;
- production from wellheads at multiple drill centres (not shown – no ensonified area at surface).

Residual underwater noise from each of the underwater noise sources have each been described previously in **Section 10**. Cumulative underwater noise estimates for these scenarios are included in **Table 10-5**. **Figure 10-8** illustrates the underwater noise ensonified areas (above 120 dB) associated with MODU activities concurrent with FPSO activities. Dashed lines represent ensonified areas associated with underwater noise sources that can be ceased under NMPs.

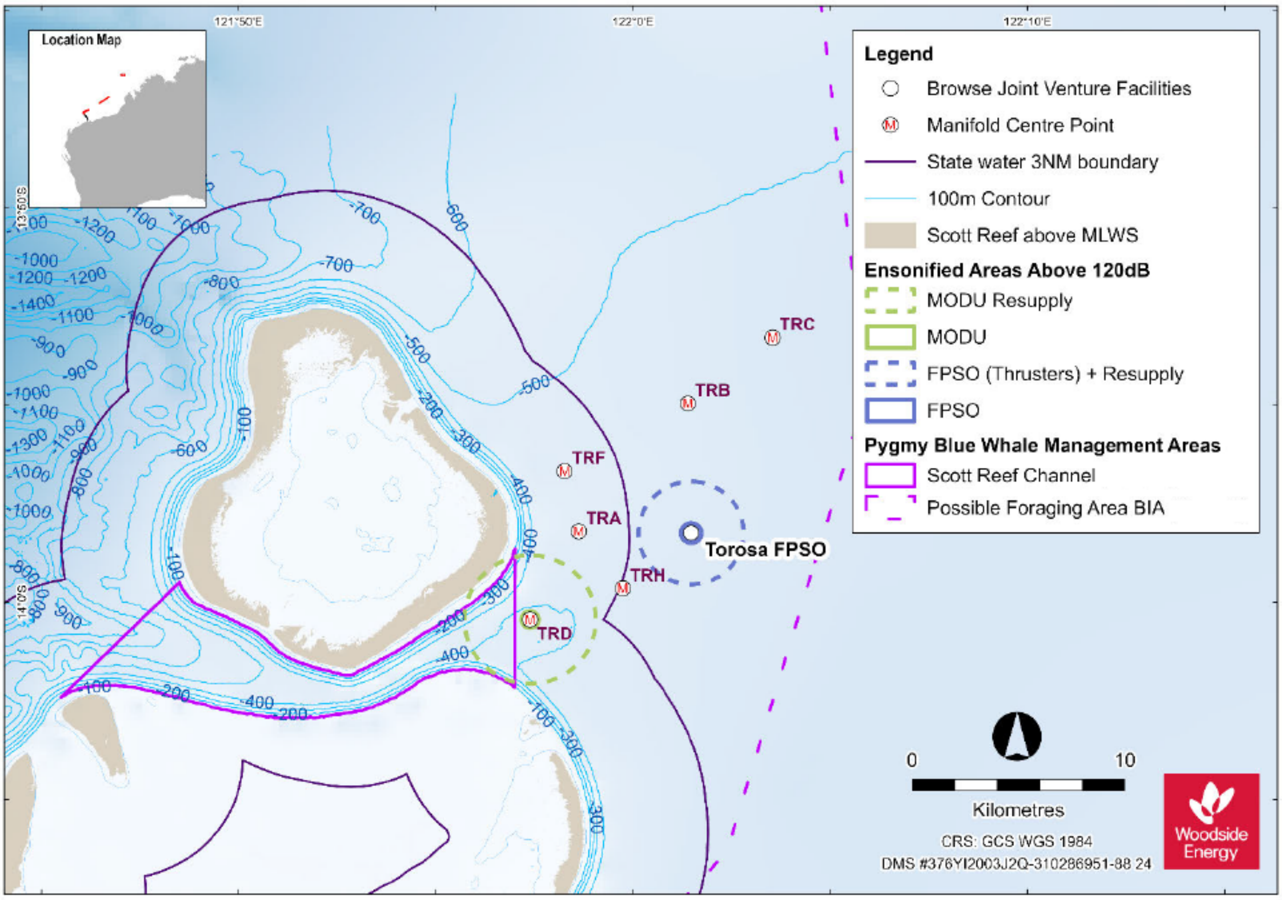

Figure 10-8 Indicative, illustrative peak cumulative ensonified areas during future subsea tieback phases, showing impact of a moored MODU drilling at TRD occurring concurrently with operation (including potential re-supply) of the Torosa FPSO.

10.6 Impulsive Noise Source Activities

Impulsive noise source activities (VSP and driven piling) will not occur during the peak pygmy blue whale seasons.

10.7Summary of Cumulative and Additive Underwater Noise in the Possible Foraging Area

Table 10-5 provides a summary of the ensonified areas above 120 dB during pygmy blue whale peak seasons. This table considers the maximum ensonified area in the possible foraging area and Scott Reef Channel for two types of continuous noise sources under two scenarios:

- **Mitigable continuous noise sources** estimates the maximum ensonified area, but where further mitigations could be applied if a whale was observed.
- **Residual continuous noise sources** estimates the maximum noise impact, but where no further mitigations are possible and represents the residual risk of behavioural disturbance.

For clarity, OSV resupply scenarios or FPSO thruster use scenarios are considered to be examples of mitigable noise sources, as DP systems/heading control systems can be deactivated upon detection of a pygmy blue whale, when safe and practical to do so. Once thrusters are deactivated, the remaining facility noise is considered residual noise.

The source level noise estimates used to derive the cumulative ensonified areas are consistent with the requirements of the Design Features and Management Measures **(Section 8)**.

Table 10-5 includes a description of the approximate durations of each of the activities. The construction activities with the largest underwater noise ensonified area estimates are restricted to the early life of the Project. Drilling and Completion activities (post Phase One) may not be consecutive, and will depend upon the timing that subsequent phase wells are required to maintain Torosa FPSO production.

Table 10-5 Cumulative ensonified area estimates (above 120 dB) for proposed Browse Project activities occurring within the Possible Foraging Area. Estimates presented as ensonified areas within the top 50m of the surface unless otherwise indicated.

Activities (mitigable source in italics)	May occur at times/locations where PBW foraging is likely to occur	Duration	Maximum Ensonified Areas from Stated Activities in the Possible Foraging Area	
			Mitigable Sources	Residual Sources[7]
Phase One drilling and completions (prior commencement of subsea & FPSO construction)				
Typical: MODU (Moored)	No	Up to two years	0.8 km² (0.01%)	0.1 km² (0.001%)
Intermittent: Moored MODU *(PSV Alongside)*			15.9 km² (0.12%)	0.1 km² (0.001%)
Phase One subsea construction and installation, concurrent with D&C				
Intermittent: IFL spurline installation within 9km of the possible foraging area + moored MODU at TRA or TRB *(with OSV alongside)*	No	Approximately two weeks.	124 km² (1.01%)	107.1 km² (0.83%)
Intermittent: SURF Installation + moored MODU at TRA or TRB *(OSV alongside)*		One week per flowline (each for two flowlines) + up to 1 month for other infrastructure, in a single year.	31.8 km² (0.26%)	15.3 km² (0.13%)
Intermittent: FPSO & SURF Hook Up Activities + moored MODU at TRA or TRB *(with OSV alongside)*		Up to three months, in a single year	35.3 km² (0.29%)	18.8 km² (0.15%)
Operations				
Continuous: FPSO *(no thrusters online)* + Wellheads	Yes	Project life (up to 44 years)	-	1.1 km² (<0.01%) received surface 3.5 km² (0.03%) - received seabed

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[7] Based on application of Noise Mitigation Plans (**Section 9**) requirements including ceasing of underwater noise sources (dynamic positioning, FPSO thrusters, MODU drilling) unless doing so would pose a risk to human safety, equipment or the vessel.

Activities (mitigable source in italics)	**May occur at times/locations where PBW foraging is likely to occur**	**Duration**	**Maximum Ensonified Areas from Stated Activities in the Possible Foraging Area**	
			Mitigable Sources	**Residual Sources**[7]
Continuous: FPSO *(using thrusters)* + Wellheads		Thrusters predicted to be required for <5% of metocean conditions	11.5 km^2 (0.09%)	1.1 km^2 (<0.01%) – surface 3.5 km^2 (0.03%) - received seabed
Intermittent: FPSO (*no thrusters, with OSV resupply*) + Wellheads		During resupply, 12 hours max (six times a month)	19.1 km^2 (0.16%)	1.1 km^2 (<0.01%) – surface 3.5 km^2 (0.03%) - received seabed
Intermittent: FPSO (*using thrusters, with OSV resupply*) + Wellheads		During resupply, 12 hours max (six times a month)	22.1 km^2 (0.18%)	1.1 km^2 (<0.01%) - surface 3.5 km^2 (0.03%) - received seabed
Intermittent: FPSO (*conducting condensate offtake*) + Wellheads		Maximum of fortnightly during project life, 24 hours per activity.	Not mitigable once offtake commences.	22.9 km^2 (0.17%) 25.3 km^2 (0.19%)
Subsea Tie-back Phases				
Continuous: Moored MODU + FPSO *(using thrusters)* + Wellheads	No	Tie back and associated drilling and completion activities may occur for a cumulative period of up to 10 years within the 44 year project life	11.9 km^2 (0.10%)	1.1 km^2 (0.01%) - surface 3.8 km^2 (0.03%) - received seabed
Intermittent: Moored MODU *(OSV resupply)* + FPSO *(Condensate Offtake*) + Wellheads			41.6 km^2 (0.34%)	25.1 km^2 (0.21%)

11. CONCLUSION

Woodside considers that the management approach outlined in this plan demonstrates, with a high level of confidence, that unacceptable impacts to pygmy blue whales will be prevented, by minimising the risk of injury to pygmy blue whales or displacement of pygmy blue whales from the Scott Reef possible foraging area, as a result of underwater noise emissions associated with the proposed Browse Project.

An overview of the residual underwater noise against criteria defining acceptability are outlined below.

11.1 Injury

Risk of injury from Impulsive Noise

The spatial and temporal controls presented in this plan ensure that all activities generating impulsive noise will either be inherently eliminated during the Project design phase and if they are required, will only occur outside of times/places where pygmy blue whales are likely to be present. A scientific monitoring program will be put in place prior to these activities occurring, to provide a thorough understanding of times and places pygmy blue whales are likely to be present in and around the Project Area. A requirement to monitor for pygmy blue whales will apply to these activities, which can be immediately ceased if a whale is sighted, on a precautionary basis.

The substitution and elimination controls are designed to ensure that activities associated with impulsive noise sources that may result in PTS and TTS do not occur spatially or temporally where pygmy blue whales may be present. This will substantially reduce the potential for injury to occur to pygmy blue whales. The mitigation controls further reduce any minor residual risk of such impacts occurring should pygmy blue whales be present outside of the spatial and temporal management areas.

Risk of injury from Vessel noise

Unlike impulsive noise which can potentially cause injury to cetaceans after only brief exposure periods, the injury thresholds (e.g. PTS, TTS) for vessel noise are based on 24 hour exposure periods (shorter exposure periods can cause PTS, but at increasingly shorter distances).

ANIMAT modelling presented within this plan further supports conclusions that risks of noise induced injury to hearing is highly unlikely to occur as a result of vessel based continuous noise and mitigations proposed to avoid impacts to foraging activity are likely to be effective at further reducing this already highly unlikely risk.

Risk of injury from Wellhead noise

Modelling completed by Duncan (2011) shows that noise levels typically fall below 120 dB re 1 uPa.m within 500 m of the wellhead drill centre. It should be noted that 500 m is a horizontal distance considering the loudest point in the water column (which for a wellhead is close to the seabed). The behavioural threshold of 120dB is not reached at the surface according to Duncan (2011) modelling, instead extending up to approximately 100 m below the surface.

The distance towards the TTS injury thresholds has been estimated as 100 m based on other modelling results presented for the proposed Browse Project. This is also defined as a horizontal distance considering the loudest point in the water column. It is not considered credible that the TTS threshold is reached at the surface given the behavioural threshold does not reach the surface. It is considered highly likely that the vertical distance to the TTS threshold would not extend beyond the behavioural threshold (i.e. 100 m below the surface).

Pygmy blue whales spend the vast majority of their time close to the sea surface (Owen et al. 2016) in depths shallower than 100 m. While a pygmy blue whale may temporarily dive within the area where TTS may occur from a well head, it is not considered credible based on known behaviour that a pygmy blue whale will reside below the 100 m water depth, within 100 m lateral distance of a wellhead drill centre, for a sufficient portion of the 24 hours that would be required for TTS to occur. Therefore, wellheads are not considered to pose a credible TTS risk to foraging or migrating pygmy blue whales.

It should also be noted that while ANIMAT modelling was not conducted on well heads specifically, ANIMAT modelling on a louder noise source (the FPSO machinery noise – 174 dB re 1 μPa·m) resulted in no simulated whales being exposed to TTS. Given the ANIMAT modelling accounts for animal behaviour and the FPSO machinery noise is close to the surface and louder than well head choke valves, the ANIMAT modelling provides further evidence that wellheads are not considered to pose a credible TTS risk to foraging or migrating pygmy blue whales.

11.2 Biologically Significant Behavioural Disturbance

It is recognised that the proposed Browse Project will result in the generation of underwater noise in excess of the recognised cetacean behavioural response threshold, which has the potential to disrupt pygmy blue whale foraging behaviour.

Accordingly, this plan has considered:

- an adaptive management approach, based on the application of the hierarchy of controls – avoidance, minimisation and detection/mitigation (**Section 6**)
- the implementation of an extensive scientific monitoring program to inform and verify environment performance standards are achieved and inform adaptive management (**Section 7**)
- the implementation of appropriate design features and management measures to prevent unacceptable impacts (summarised in **Section 8**)
- the implementation on Noise Mitigation Plans to put in place in-field adaptive management and cease underwater noise sources if a nearby whale is detected (**Section 9**)
- the extent, intensity and duration of residual underwater noise within the Scott Reef possible foraging area, including residual and cumulative impacts after the application of controls (summarised in **Section 10**).

Best practice management measures in accordance with a precautionary approach have been established within this plan and successful implementation will ensure that, with a high degree of certainty, the anthropogenic noise from the proposed Browse Project will be managed such that any blue whale will be able to continue to utilise the BIA without injury, and no blue whale will be displaced from a foraging area. In this way, the proposed Browse Project will not be inconsistent with the CMP.

For short-term construction activities, the largest anticipated ensonified area at any time is approximately 308km^2 at surface based on a rigid pipelay vessel. This construction activity, along with Drilling and Completions, subsea flowline installation/subsea construction and impulsive noise sources, will not occur at times/locations when pygmy blue whale foraging is likely to occur.

After the initial construction phase, the total areal extent of the Scott Reef possible foraging area ensonified above 120 dB and where no further mitigations based on whale sightings are possible, is reduced to:

- ~1.0 km^2 at sea surface (<0.01% of the possible foraging area) or 3.5 km^2 at seabed (0.03%) during normal operations
- ~22.4 km^2 at sea surface (~0.17% of the possible foraging area) or 24.8 km^2 (0.19%) at seabed during FPSO condensate offtake (24 hour operation every 2-4 weeks).

In the context of the overall size of the Possible Foraging Area (>12,000km^2), it is not objectively credible that highly localised residual underwater noise represents a threat of serious damage to blue whale utilisation of Scott Reef, based on the available scientific information demonstrating limited Pygmy Blue Whale utilisation of Scott Reef for foraging. Nor is it objectively credible that the nature and extent of noise represents a threat of irreversible damage to their ongoing opportunity to forage at Scott Reef/loss of foraging opportunities significant enough to result in reduced population fitness.

While it is credible that an individual foraging PBW that approaches to within very close proximity to Proposal vessels or infrastructure could be disturbed, based on extensive data collected by Woodside, the risk of this occurring is remote. It is not objectively credible to conclude that impacts to individual foraging whales resulting from underwater noise from Proposal activities could manifest in biologically significant behavioural disturbance, or adverse outcomes at the population level.

12. PLAN REVIEW

In order to ensure the effectiveness and efficiency of the management measures outlined in this plan, as well as the outcomes of scientific monitoring program it is important to allow for periodic review of the overall management plan and for revisions, if approved by the Minister, to be implemented.

Such reviews may include but is not limited to the following considerations:

- Modification of any of the proposed management measures following implementation and review of effectiveness.
- Removal, update or modification to the Blue Whale CMP
- Review of spatial extent of possible foraging area and/or management zones as a result of monitoring
- Review of expected timing of presence of pygmy blue whales and definition of peak and shoulder periods for migratory seasons following monitoring outcomes
- Review of the scientific monitoring program with reference to design (number of monitoring stations, duration, survey techniques and knowledge gaps), outcomes and expert opinion
- Publication of peer-reviewed data that contributes to the knowledge of the EIO pygmy blue whale population and data that supports modification to proposed management measures and/or removes uncertainty associated with application of a precautionary approach.

In absence of any of the above review triggers, the plan will be reviewed and updated at least every five years.

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14. ACRONYMS

Acronym	Meaning
2C	Contingent resources
2TL	Second trunkline
ASV	Autonomous underwater vehicle
AUV	Autonomous surface vehicle
BIA	Biologically important area
BJV	Browse Joint Venture
BTL	Browse Trunkline
Cal/Brec	Calliance and Brecknock fields
CMP	Conservation Management Plan
DAWE	Department of Agriculture, Water and the Environment
DP	Dynamic positioning
EIA	Environmental impact assessment
EIO	East Indian Ocean
EIOPBW	East Indian Ocean pygmy blue whales
EIS	Environmental Impact Statement
EP	Environment Plan
EP Act	*Western Australia Environmental Protection Act* 1986
EPBC Act	*Environment Protection and Biodiversity Conservation Act* 1999
EPO	Environment Performance Objective
EQMP	Environmental Quality Management Plan
ERD	Environmental Review Document
FAQ	Frequently asked questions
FCGT	Flood, clean, gauge and test
FPSO	Floating Production Storage and Offloading
HUC	Hook up and commissioning
IFL	Interfield line (rigid pipeline between Torosa and Calliance FPSO)
IMMR	Inspection, maintenance, monitoring and repair activities
MMscfd	Million standard cubic feet per day
MODU	Mobile offshore drilling units
MSL	Mean source level
NCVA	National Conservation Values Atlas
NOPSEMA	National Offshore Petroleum Safety and Environment Authority
NRC	North Rankin Complex
NWS	North West Shelf

Acronym	Meaning
NWSJV	NWS Joint Venture
OSV	Offshore support vessel
PAM	Passive acoustic monitoring
PFA	Possible Foraging Area
PTS	Permanent Threshold Shift
PBW	Pygmy Blue Whale
RFSU	Ready for start up
Required for SOLAS	In situations where the vessel master considers that complying with a requirement of this plan would adversely affect the safety or security of the vessel or its passengers or crew, or in situations where the vessel master is bound to provide assistance (under SOLAS Chapter V) upon receiving a distress signal from any source that persons are in distress at sea, the requirement does not apply.
SEL	Sound exposure level
SPL	Sound pressure level
SSV	Sound source verification
SURF	Subsea, Umbilicals, Risers Flexibles
Surface waters	Approximately top 30m of the water column
tcf	Trillion cubic feet
TTS	Temporary Threshold Shift
VSP	Vertical Seismic Profiling
WA	Western Australia
NMP	Noise Mitigation Plans

Appendix A - Woodside Browse to NWS Vessel Noise Acoustic Modelling (Green *et al* 2022a)

Woodside Browse to NWS Vessel Noise

Acoustic Modelling

JASCO Applied Sciences (Australia) Pty Ltd

13 July 2022

Submitted to:

[redacted]
Woodside Energy
[redacted]

Authors:

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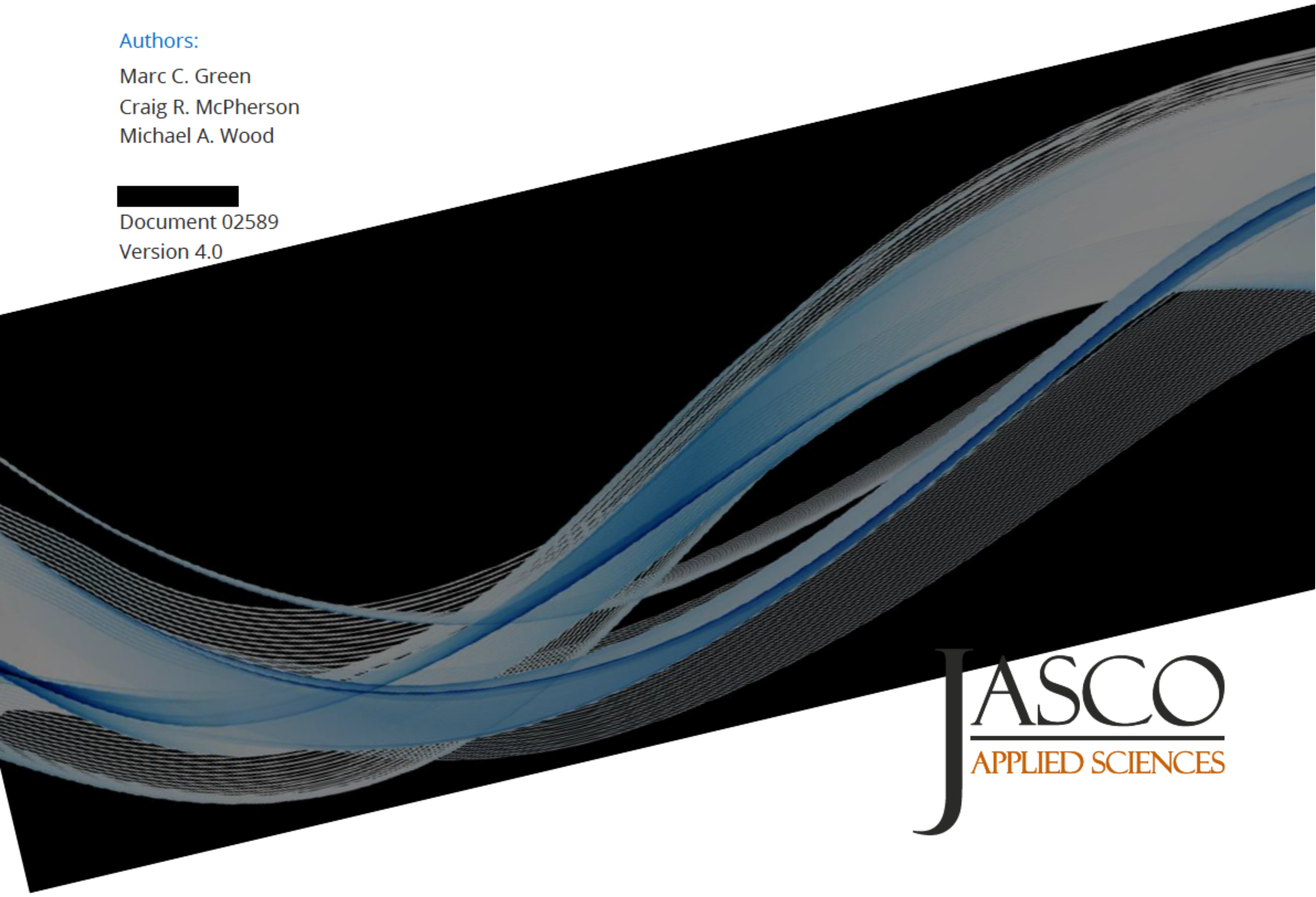

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Contents

Figures

Tables

Executive Summary

The Browse Joint Venture (BJV) proposes to develop the Brecknock, Calliance, and Torosa fields (collectively known as the Browse resources) via the development drilling of wells and the installation of a subsea production system that will supply two 1100 million standard cubic feet per day (annual daily export average) Floating Production Storage and Offloading (FPSO) facilities. The Browse Project gas will be transported from the FPSO facilities to the existing NWS Project infrastructure via an approximately 900 km long trunkline. Each FPSO will have a turret mooring system that will be stabilised using mooring lines secured to the seabed by piles. JASCO Applied Sciences previously modelled pile driving operations, vertical seismic profiling (VSP) during drilling operations, Mobile Offshore Drilling Unit (MODU), FPSO operations and Operational Support Vessel (OSV) operations, with the results presented in McPherson et al. (2019).

The BJV provided revised information about the MODU and FPSO operations for the present modelling study, which considers the following scenarios:

- The operations of a Mobile Offshore Drilling Unit (MODU) using only four thrusters at TRA and TRD drill centre locations (as opposed to eight).
- The operations of a MODU in a ‘moored’ configuration using no thrusters.
- The resupply of the MODU during drilling operations at TRA and TRD drill centre locations.
- FPSO operational noise for the Torosa FPSO without heading control, with heading control (thrusters operating), and with optimised heading control.
- Torosa FPSO operational noise during offtake, including the FPSO without heading control, an Offshore Support Vessel (OSV) near the FPSO, and a noiseless condensate tanker.
- Aggregate scenarios that include MODU drilling operations at TRD and the Torosa FPSO during offtake operations.

The objective of this modelling study was to determine ranges to acoustic exposure thresholds representing the best available science for permanent threshold shift (PTS), temporary threshold shift (TTS), and behavioural disturbance of marine fauna including marine mammals, turtles, and fish.

Acoustic fields caused by pressure were modelled and are presented as sound pressure levels (SPL) and accumulated sound exposure levels (SEL) as appropriate for noise effect criteria for continuous (vessel) noise sources. The effects of range-dependent environmental properties on sound propagation in the study area were accounted for by the numerical models.

The modelled sources are as follows:

- *An FPSO facility* that is 370 m long and 67 m wide. This was modelled under:
  - Typical operations, with no heading control and no offtake, only operating processing and associated equipment.
  - Heading control (thrusters operating), representative of typical operational conditions.
  - Heading control (thrusters operating) with optimised thrusters, representative of typical operational conditions.
  - Offtake, during which the FPSO is only operating processing and associated equipment, with an OSV under DP located 700 m behind the FPSO, and a noiseless condensate tanker located between the two.
- *A representative MODU* that is 100 × 80 m, under DP, representative of typical operational loads during 1-year (non-cyclonic) return interval metocean conditions. This was modelled using:
  - Four thruster sources operating at 40% capacity.
  - A central machinery source, representative of a typical drilling operation.

- *A representative OSV*, a DP vessel that is 92.95 m long (vessel design based on the Marin Teknikk MT6016 hull) under DP, representative of typical operational loads during maximum safe operating conditions and resupply operations. This was modelled using five thruster sources operating at a defined capacity, based on the specification of the *Fugro Etive*, as follows:
    - Two Rolls-Royce AZP100 thrusters.
    - Two Rolls Royce TT 2200 DPN thrusters.
    - One Rolls-Royce AZP1001 thruster.

The analysis considered multiple commonly used effect criteria, with the key results of the acoustic modelling summarised below.

Marine Mammals

- The results for the United States (US) National Marine Fisheries Service (NMFS 2018) criteria applied for marine mammal PTS and TTS for vessels are assessed here for a 24 hour period. Vessels are considered to be active continuously across the 24 hour period unless specified otherwise in the table heading. The maximum ranges to PTS are summarised in Tables 1 and 2.
- The maximum ranges to the US National Oceanic and Atmospheric Administration (NOAA 2019) marine mammal behavioural response criterion of 120 dB re 1 µPa (SPL) are summarised in Tables 3 and 4.
- For the aggregate scenario considering both TRD MODU drilling and FPSO offtake operations, it was found that due to the separation between the sites, ranges to PTS and TTS thresholds were unaltered compared to the individual operations. Maximum range to the behavioural response level was increased, and this is shown in Table 5.

Table 1. *Marine mammal SEL$_{24h}$, TRA and TRD Drill Centres*: Maximum (R_{max}) horizontal ranges (km) to modelled maximum-over-depth PTS thresholds from NMFS (2018).

Hearing group	Threshold for PTS, SEL$_{24h}$ (dB re 1 µPa²s)[a]	Range R_{max} (km)					
		MODU (on DP)	MODU (Moored)	OSV (6 h)	OSV (12 h)	MODU Resupply (OSV 6 h)	MODU Resupply (OSV 12 h)
TRA Drill Centre							
LF cetaceans	199	<0.05	—	<0.05	0.06	0.06	0.06
MF cetaceans	198	<0.05	—	<0.05	<0.05	<0.05	<0.05
HF cetaceans	173	0.09	<0.05	0.06	0.10	0.10	0.11
TRD Drill Centre							
LF cetaceans	199	0.06	<0.05	0.06	0.06	0.06	0.06
MF cetaceans	198	0.06	<0.05	<0.05	<0.05	0.06	0.06
HF cetaceans	173	0.09	<0.05	0.06	0.09	0.10	0.11

[a] Frequency weighted.

Table 2. *Marine mammals, SEL_{24h}, activities at Torosa FPSO location*: Maximum (R_{max}) horizontal ranges (km) to modelled maximum-over-depth PTS thresholds from NMFS (2018).

Hearing group	Threshold for PTS, SEL_{24h} (dB re 1 μPa^{2}s)[a]	Range R_{max} (km)		
		FPSO, Heading Control	FPSO, Heading Control (Optimised Thrusters)	FPSO Offtake
LF cetaceans	199	<0.05	<0.05	0.07
MF cetaceans	198	<0.05	—	<0.05
HF cetaceans	173	0.06	<0.05	0.11

[a] Frequency weighted.

A dash indicates the level was not reached.

FPSO offtake includes an FPSO, a noiseless condensate tanker and an OSV

Table 3. *Marine mammal behaviour, TRA and TRD Drill Centres*: Summary of maximum behavioural disturbance ranges.

SPL (L_p; dB re 1 μPa)	Range R_{max} (km)			
	MODU (under DP)	MODU (Moored)	OSV	MODU Resupply
TRA Drill Centre				
120[a]	4.49	0.49	2.21	4.95
TRD Drill Centre				
120[a]	4.10	0.49	3.14	5.49

[a] Threshold for marine mammal behavioural response to continuous noise (NOAA 2019).

Table 4. *Marine mammal behaviour, activities at Torosa FPSO location*: Summary of maximum behavioural disturbance ranges.

SPL (L_p; dB re 1 μPa)	Range R_{max} (km)		
	FPSO, Heading Control	FPSO, Heading Control (Optimised Thrusters)	FPSO Offtake
120[a]	2.82	1.67	2.67

[a] Threshold for marine mammal behavioural response to continuous noise (NOAA 2019).

FPSO offtake includes an FPSO under DP, a noiseless condensate tanker and an OSV.

Table 5. *Marine mammal behaviour, Aggregate Scenario*: MODU under DP at TRD and Torosa FPSO Offtake, summary of maximum behavioural disturbance ranges.

SPL (L_p; dB re 1 μPa)	Range R_{max} (km)
120[a]	4.68

[a] Threshold for marine mammal behavioural response to continuous noise (NOAA 2019).

Sea Turtles

The maximum ranges for the Finneran et al. (2017) criteria applied for sea turtles are summarised in Tables 6 and 7. There were no significant differences in ranges for the aggregate scenario compared with the individual operations.

Table 6. *Sea turtle SEL_{24h}, TRA and TRD Drill Centres*: Maximum-over-depth ranges (in km) to PTS threshold.

Threshold for PTS, SEL_{24h} (dB re 1 µPa²s)[a]	Range R_{max} (km)					
	MODU (under DP)	MODU (Moored)	OSV (6 h)	OSV (12 h)	MODU Resupply (OSV 6h)	MODU Resupply (OSV 12 h)
TRA Drill Centre						
220[b]	<0.05	—	<0.05	<0.05	<0.05	<0.05
TRD Drill Centre						
220[b]	0.06	—	—	<0.05	0.06	0.06

[a] Frequency weighted.

[b] Threshold for turtle-weighted SEL_{24h} (Finneran et al. 2017).

A dash indicates the level was not reached.

Table 7. *Sea turtle SEL_{24h}, activities at Torosa FPSO location*: Maximum-over-depth ranges (in km) to PTS threshold.

Threshold for PTS, SEL_{24h} (dB re 1 µPa²s)[a]	Range R_{max} (km)		
	FPSO, Heading Control	FPSO, Heading Control (Optimised Thrusters)	FPSO Offtake
220[b]	—	—	<0.05

[a] Frequency weighted.

[b] Threshold for turtle-weighted SEL_{24h} (Finneran et al. 2017).

A dash indicates the level was not reached.

Fish

- Sound produced by the operations could cause physiological effects and recoverable injury to some fish species, but only if the animals are in close proximity to the sound sources (within a planar range of 60 m) for 48 hours. Temporary impairment due to TTS could occur at similar short ranges if fish remain at the same range for long periods of time (12 hours). The ranges are very similar for all scenarios.
- There is no increased risk to fish from aggregate scenarios.

1. Introduction

JASCO Applied Sciences (JASCO) performed a modelling study of underwater sound levels associated with the Browse to North West shelf (NWS) Project development of the Brecknock, Calliance, and Torosa fields (collectively known as the Browse resources) by the Browse Joint Venture (BJV). This development will involve drilling wells and installing a subsea production system that will supply two 1100 million standard cubic feet per day (annual daily export average) Floating Production Storage and Offloading (FPSO) facilities. Gas will be transported from the FPSO facilities to the existing NWS Project infrastructure via an approximately 900 km long trunkline. Each FPSO will have a turret mooring system that will be stabilised using mooring lines secured to the seabed by piles. JASCO previously modelled pile driving operations, vertical seismic profiling (VSP) during drilling operations, Mobile Offshore Drilling Unit (MODU), and FPSO operations and Operational Support Vessel (OSV) operations. This previous work was presented in McPherson et al. (2019).

The BJV provided revised information about the MODU and FPSO operations for the present modelling study, which considers the following scenarios:

- The operations of a Mobile Offshore Drilling Unit (MODU) using only four thrusters at TRA and TRD drill centre (as opposed to eight).
- The operations of a MODU in a ‘moored’ configuration using no thrusters.
- The resupply of the MODU during drilling operations at TRA and TRD drill centres.
- FPSO operational noise for the Torosa FPSO without heading control, with heading control (thrusters operating), and with optimised heading control.
- Torosa FPSO operational noise during offtake, including the FPSO without heading control, an Offshore Support Vessel (OSV) near the FPSO and a noiseless condensate tanker.
- Aggregate scenarios that include MODU operations at the TRD drill centre and the Torosa FPSO during offtake operations.

The modelling study specifically assessed ranges from operations where underwater sound levels reached thresholds corresponding to various levels of impact on marine fauna. The animals considered here included marine mammals (pygmy blue whales, *Balaenoptera musculus brevicauda*), sea turtles, and fish (including fish eggs and larvae). Due to the variety of species considered, there are several thresholds for evaluating effects, including: mortality, injury, temporary reduction in hearing sensitivity, and behavioural disturbance.

The modelling methodology considered source directivity and range-dependent environmental properties. Estimated underwater acoustic levels are presented as sound pressure levels (SPL, L_p), and or accumulated sound exposure levels (SEL, L_E) as appropriate for different noise effect criteria for non-impulsive (continuous) noise sources.

The geographic coordinates for the modelled sites are provided in Table 8 and an overview of the modelling area is shown in Figure 1.

Table 8. Location details for the modelled sites

Site	Source	Latitude (S)	Longitude (E)	MGA (GDA94), Zone 51		Water depth (m)
				X (m)	Y (m)	
TRA Drill Centre	MODU (centre)	13° 58′ 12.50″	121° 58′ 37.70″	389521	8455338	425
	OSV (centre)	13° 58′ 12.49″	121° 58′ 35.70″	389461	8455338	425
TRD Drill Centre	MODU (centre)	14° 00′ 26.64″	121° 57′ 23.58″	387315	8451207	392
	OSV (centre)	14° 00′ 26.63″	121° 57′ 21.58″	387255	8451207	392
Torosa FPSO	FPSO (centre)	13° 58′ 15.06″	122° 01′ 28.53″	394647	8455281	463
	OSV (centre)	13° 58′ 14.94″	122° 00′ 59.03″	393762	8455281	460

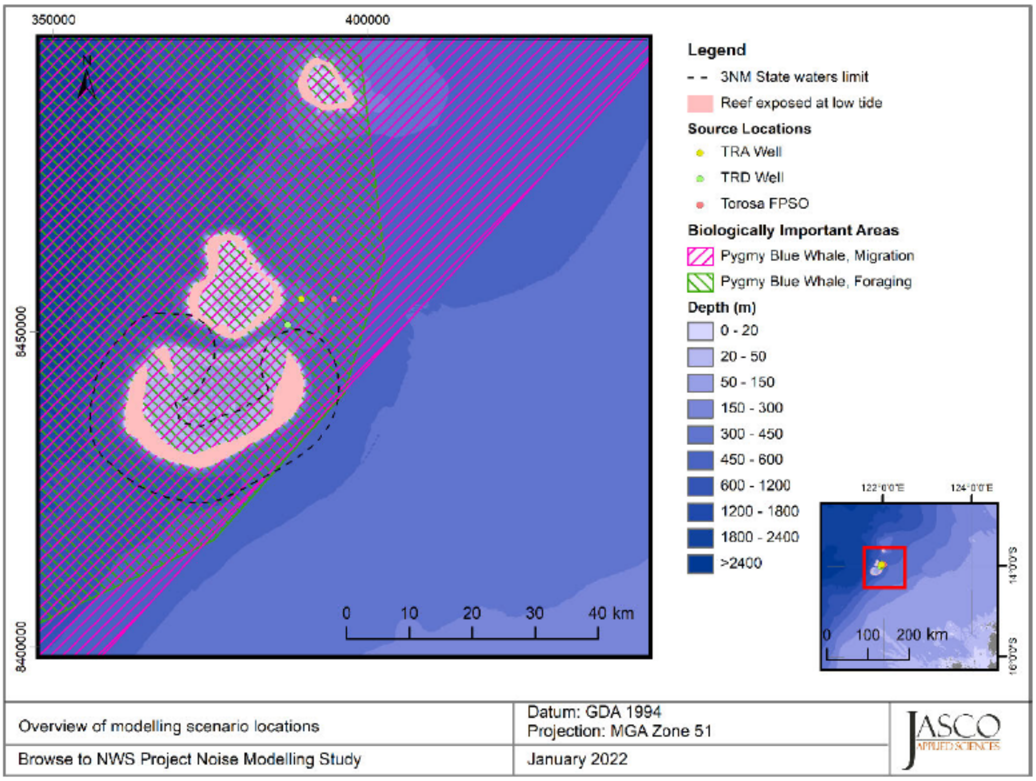

Figure 1. Overview of the modelled area and local features

1.1. Acoustic Modelling Scenario Details

The modelled sources are as follows:

- *An FPSO facility* that is 370 m long and 67 m wide. This was modelled under:
    - Typical operations, with no heading control and no offtake, only operating processing and associated equipment
    - Heading control (thrusters operating), representative of typical operational conditions
    - Heading control (thrusters operating) with optimised thrusters, representative of typical operational conditions
    - Offtake, during which the FPSO is only operating processing and associated equipment

- *A representative MODU* that is 100 × 80 m under DP, representative of typical operational noise during 1-year (non-cyclonic) return interval metocean conditions. This was modelled using:
    - Four thruster sources operating at 40% capacity
    - A central machinery source, representative of a typical drilling operation
- *A representative MODU* that is 100 × 80 m moored (no DP), representative of typical operational noise during drilling. This was modelled using:
    - A central machinery source, representative of a typical drilling operation.
- *A representative OSV*, a DP vessel 92.95 m long (vessel design based on the Marin Teknikk MT6016 hull) under DP, representative of typical operational noise during maximum safe operating conditions and resupply operations. This was modelled using five thruster sources operating a defined capacity, based on the specification of the *Fugro Etive*, as follows:
    - Two Rolls-Royce AZP100 thrusters.
    - Two Rolls Royce TT 2200 DPN thrusters.
    - One Rolls-Royce AZP1001 thruster.

These vessels were modelled in varying configurations at the three different locations shown in Figure 1. Scenarios are summarised in Table 9.

At both TRA and TRD drill centress, the OSV is positioned directly adjacent to the MODU, holding station on the MODU’s west side (Figure 2). Note that this figure shows co-ordinates for the TRA drill centre, but the relative vessel positioning is identical at the TRD drill centre. Resupply was only modelled for the DP MODU, not the moored MODU.

At the Torosa FPSO location, the OSV is positioned 700 m due west of the centre point of the FPSO, representative of an offtake scenario. This scenario also includes a tanker vessel, which has been treated as silent in the modelling. Figure 3 shows the layout for the Torosa location.

Table 9. Modelled scenarios

Scenario	Description	Sources	Length of operation
TRA drill centre			
1(a)	MODU drilling (under DP)	MODU drilling and thrusters (4 × 40%)	24 h
1(b)	MODU drilling (moored)	MODU drilling, no thrusters	24 h
2	Offshore Support Vessel	Support vessel (DP)	6 and 12 h
3	MODU resupply	MODU drilling and thrusters (4 × 40%) Support vessel (DP)	
TRD drill centre			
4(a)	MODU drilling (under DP)	MODU drilling and thrusters (4 × 40%)	24 h
4(b)	MODU drilling (moored)	MODU drilling, no thrusters	24 h
5	Offshore Support Vessel	Support vessel (DP)	6 and 12 h
6	MODU resupply	MODU drilling and thrusters (4 × 40%) Support vessel (DP)	
Torosa FPSO location			
7(a)	FPSO using heading control	FPSO thrusters and topsides machinery	24 h
7(b)	FPSO using optimised heading control	Optimised FPSO thrusters and topsides machinery	
8	FPSO offtake	FPSO with topsides machinery Silent Tanker Support vessel (DP)	
TRD drill centre and Torosa FPSO locations			
9	MODU drilling at TRD, Torosa FPSO Offtake	MODU drilling and thrusters (4 × 40%) Support vessel (DP) FPSO with topsides machinery Silent Tanker	24 h

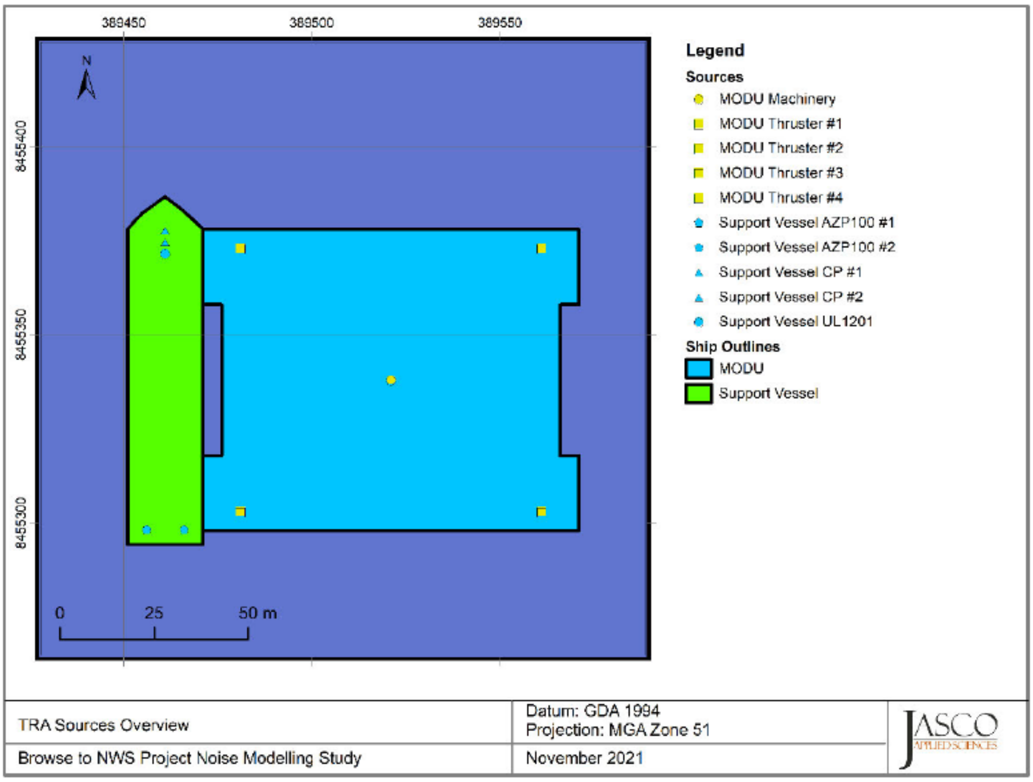

Figure 2. Overview of source layout at the TRA drill centre. Relative positioning of vessels is identical to that at the TRD drill centre. Locations for all sources are shown.

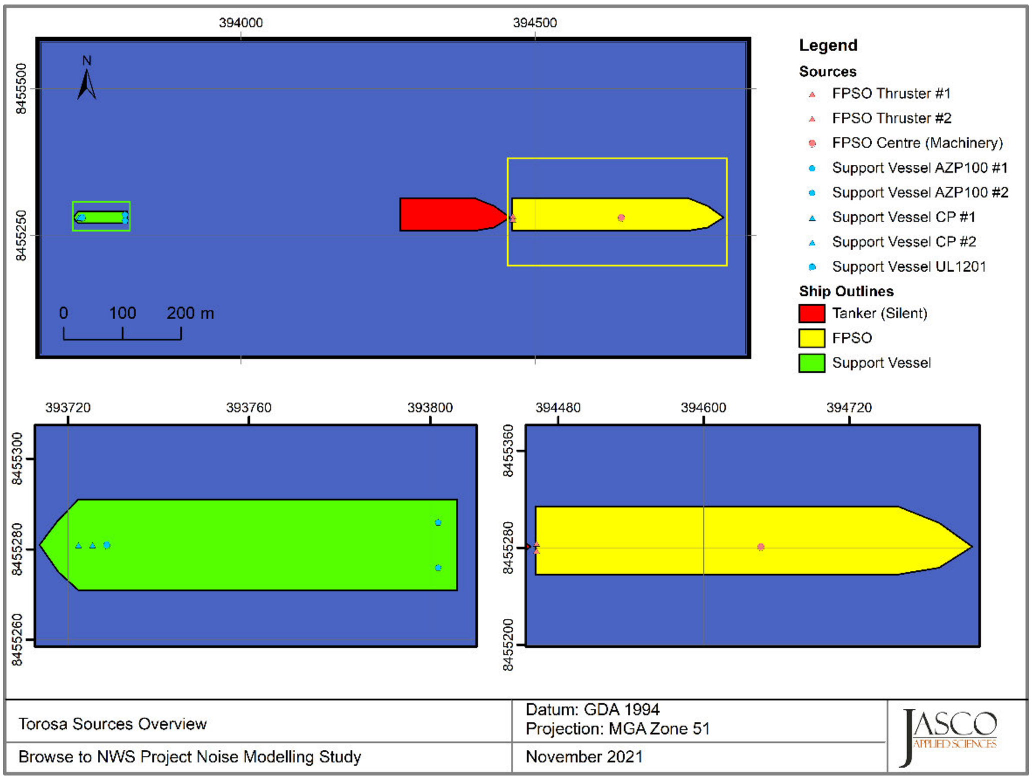

Figure 3. Overview of source layout at Torosa FPSO location, with detail on specific source positioning for FPSO and OSV. Locations for all sources are shown.

2. Noise Effect Criteria

To assess the potential impacts of a sound-producing activity, it is necessary to first establish exposure criteria (thresholds) for which sound levels may be expected to have a negative impact on animals. Whether acoustic exposure levels might injure or disturb marine fauna is an active research topic. Since 2007, several expert groups have developed SEL-based assessment approaches for evaluating auditory injury, with key works including Southall et al. (2007), Finneran and Jenkins (2012), Popper et al. (2014), and the United States National Marine Fisheries Service (NMFS 2018). The number of studies that investigate the level of behavioural disturbance to marine fauna by anthropogenic sound has also increased substantially.

Several sound level metrics, such as PK, SPL, and SEL, are commonly used to evaluate noise and its effects on marine life (see Appendix A.3). In this report, the duration of the SEL accumulation is integrated over the operational time periods for each vessel, as defined in Table 9.

Appropriate subscripts indicate any applied frequency weighting (Appendix A.3.3). The acoustic metrics in this report reflect the updated ANSI and ISO standards for acoustic terminology, ANSI S1.1 (R2013) and ISO 18405:2017 (2017).

This study applies the following noise criteria (Sections 2.1–2.2 and Appendix A.3.1), chosen for their acceptance by regulatory agencies and because they represent current best available science:

- Frequency-weighted accumulated sound exposure levels (SEL; $L_{E,24h}$) from NMFS (2018) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals. This criteria was applied for consistency with previous work (McPherson et al. 2019).
- Marine mammal behavioural threshold based on the current interim U.S. National Oceanic and Atmospheric Administration (NOAA 2019) criterion for marine mammals of 120 dB re 1 µPa SPL (L_p) for non-impulsive sound sources. This is identical to the previously applied behavioural response threshold, however the reference has been updated.
- Sound exposure guidelines for fish, fish eggs, and larvae (Popper et al. 2014).
- Frequency-weighted accumulated sound exposure levels (SEL; $L_{E,24h}$) from Finneran et al. (2017) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in sea turtles.

2.1. Marine Mammals

The criteria applied in this study to assess possible effects of non-impulsive sources on marine mammals are summarised in Table 10; Cetaceans (low-, mid-, and high-frequency) were identified as the hearing groups requiring assessment. Details on thresholds related to auditory threshold shifts or hearing loss and behavioural response are provided in A.3, with frequency weighting explained in detail in Appendix A.3.3. Of particular note, whilst the newly published Southall et al. (2021) provides recommendations and discusses the nuances of assessing behavioural response, the authors do not recommend new numerical thresholds for onset of behavioural responses for marine mammals.

Table 10. Criteria for effects of non-impulsive noise exposure, including vessel noise on marine mammals: SPL and Weighted SEL_{24h} thresholds.

Hearing group	NOAA (2019)	NMFS (2018)	
	Behaviour	PTS onset thresholds (received level)	TTS onset thresholds (received level)
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)
LF cetaceans	120	199	179
MF cetaceans		198	178
HF cetaceans		173	153

L_p denotes sound pressure level period and has a reference value of 1 µPa.
L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^{2}s.

2.2. Fish, Sea Turtles, Fish Eggs, and Fish Larvae

In 2006, the Working Group on the Effects of Sound on Fish and Turtles was formed to continue developing noise exposure criteria for fish and sea turtles based on work began by a NOAA panel two years earlier. The Working Group developed guidelines with specific thresholds for different levels of effects for several species groups (Popper et al. 2014). The guidelines define quantitative thresholds for three types of immediate effects:

- Mortality, including injury leading to death.
- Recoverable injury, including injuries unlikely to result in mortality, such as hair cell damage and minor haematoma.
- TTS.

Masking and behavioural effects can be assessed qualitatively, by assessing relative risk rather than by specific sound level thresholds. However, as these depend upon activity-based subjective ranges, these effects are not addressed in this report, and are included in Table 11 for completeness only. Because the presence or absence of a swim bladder has a role in hearing, fish susceptibility to injury from noise exposure depends on the species and the presence and possible role of a swim bladder in hearing. Thus, different thresholds were proposed for fish without a swim bladder (also appropriate for sharks and applied to whale sharks in the absence of other information), fish with a swim bladder not used for hearing, and fish that use their swim bladders for hearing. Sea turtles, fish eggs, and fish larvae are considered separately.

Table 11 lists the relevant effects thresholds from Popper et al. (2014) for shipping and continuous noise. Some evidence suggests that fish sensitive to acoustic pressure show a recoverable loss in hearing sensitivity, or injury when exposed to high levels of noise (Scholik and Yan 2002, Amoser and Ladich 2003, Smith et al. 2006); this is reflected in the SPL thresholds for fish with a swim bladder involved in hearing. Finneran et al. (2017) presented revised thresholds for turtle injury, considering frequency weighted SEL, which have been applied in this study (Table 12).

Table 11. Criteria for vessel noise exposure for fish, adapted from Popper et al. (2014).

Type of animal	Mortality and Potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB SPL for 48 h	158 dB SPL for 12 h	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Sea turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Fish eggs and fish larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

Sound pressure level dB re 1 µPa.
Relative risk (high, moderate, low) is given for animals at three ranges from the source defined in relative terms as near (N), intermediate (I), and far (F).

Table 12. Acoustic effects of continuous noise on sea turtles, weighted SEL_{24h}, Finneran et al. (2017).

PTS onset thresholds (received level)	TTS onset thresholds (received level)
Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)
204	189

L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^{2}s.

3. Methods

The operations considered in this study will occur at the Torosa fields, specifically at the TRA and TRD drill centres and FPSO location, at depths ranging from 390–463 m. Environmental parameters (bathymetry, sound speed profile and geoacoustics) from McPherson et al. (2019) was reused. Details are provided in Appendix C.2.

For the purposes of the environmental impact assessment process, the Browse Joint Venture have proposed acoustic source parameters for certain vessels under specific conditions. Where the BJV have proposed acoustic source parameters, these are provided on the basis of underwater radiated noise source modelling commissioned from DNV's Noise and Vibration division. The underwater radiated noise source modelling considers specific dynamic positioning and heading control system designs of representative vessels under a range of different operating conditions. The BJV have conservatively selected the thruster utilisation for modelling based on marine operational advice regarding specific sea state conditions. Further information regarding the development of the BJV's acoustic source parameters can be found in the BJV's Pygmy Blue Whale Management Plan.

3.1. Acoustic Source Parameters

3.1.1. Mobile Offshore Drilling Unit

Sound source locations and spectrum estimates for the MODU sources were based on the *Seadrill West Sirius*, which is equipped with eight Rolls-Royce UUC 355 thrusters (Figure 4).

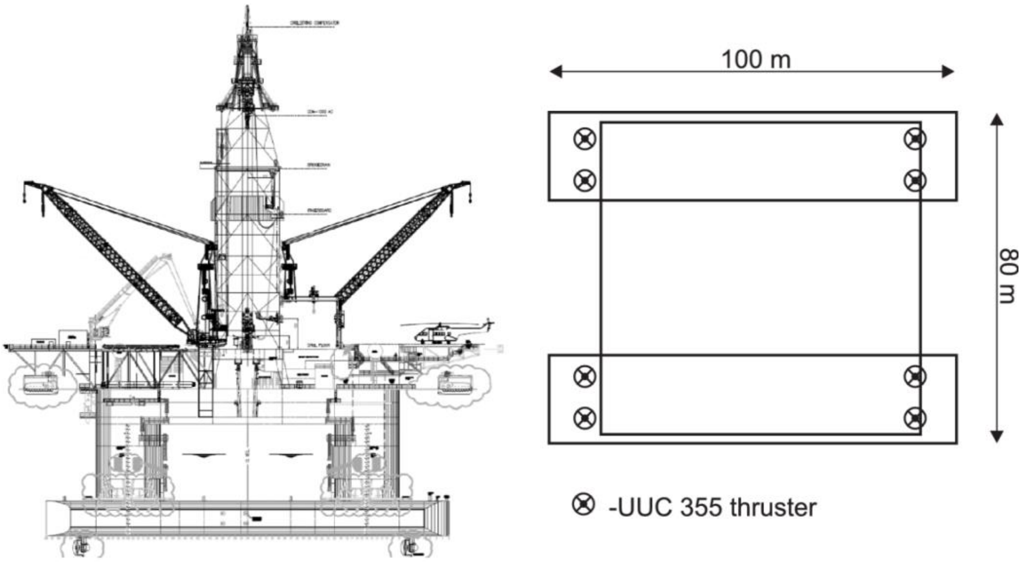

Figure 4. *Seadrill West Sirius* technical drawing showing thruster locations

This study modelled each MODU under dynamic positioning as five sources, representing four active thrusters running at 40% capacity, plus a source for noise incurred by drilling operations. The source levels for the thrusters were theoretically determined, and provided by the Browse Joint Venture (BJV), whilst the spectrum for drilling and machinery noise was taken from a recorded spectrum reported by Austin et al. (2018) for the *Transocean Polar Pioneer*, a similar semi-submersible drilling unit. Broadband source levels are 170.7 dB re 1 µPa and 176.5 dB re 1 µPa for the machinery noise and thrusters, respectively, making the combined broadband source level 182.8 dB re 1 µPa. The moored MODU was represented by the machinery/drilling noise only. The Figure 5 shows the decidecade band monopole source levels.

Machinery noise was modelled as a point source located at the centre of the MODU with a source 12.6 m depth based on 0.7 × ship draft (18 m for *West Sirius*) as specified in ISO 17208-1 (2016). Source depths for the thrusters were set to equal the draft, at 18 m.

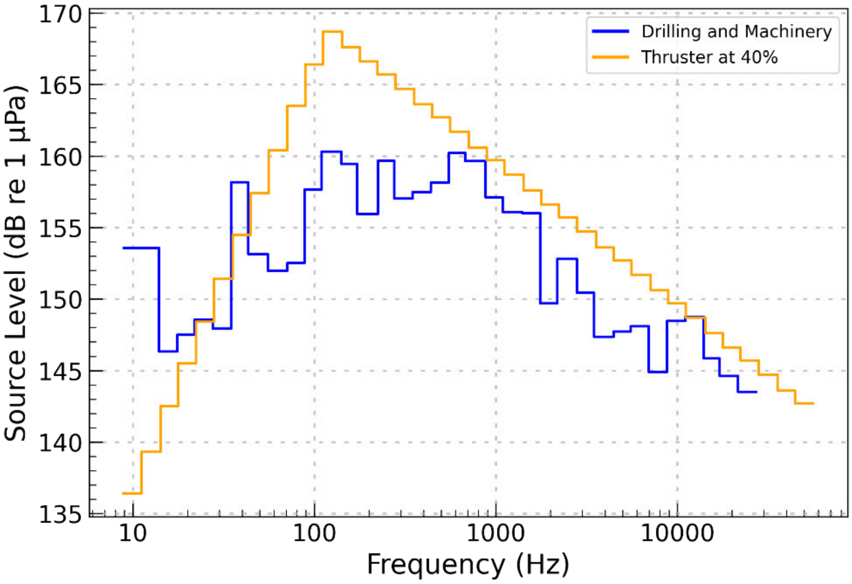

Figure 5. Decidecade band monopole source levels for MODU sources. Drilling and machinery levels from recorded spectrum of *Transocean Polar Pioneer*, 40% thrusters from theoretical data provided by the BJV.

3.1.2. Offshore Support Vessel

Sound source levels for the OSV were based on the *Fugro Etive*, a general purpose vessel 92.95 m in length, and 19.7 m in breadth, featuring two stern azipull thrusters (Rolls-Royce AZP100), two bow controllable pitch thrusters (Rolls-Royce TT 2200 DPN), and a retractable azimuthing thruster (Rolls-Royce UL1201).

For the FPSO offtake, each thruster was modelled as an individual source, operating at 40% capacity, from theoretically developed source levels provided by the BJV. Broadband source levels for these thrusters are 181.2, 174.7, and 174.9 dB re 1 µPa, respectively, giving a total broadband SL of 185.5 dB re 1 µPa. Source level spectra are shown in Figure 6.

For the MODU resupply scenarios, each thruster was modelled as an individual source, with the bow and retractable thrusters operating at 40% capacity, and the stern azipull thrusters operating at 20%, from theoretically developed source levels provided by the BJV. Broadband source levels for these thrusters are 173.3, 174.7, and 174.9 dB re 1 µPa, respectively, giving a total broadband SL of 181.3 dB re 1 µPa. Source level spectra are shown in Figure 7.

The BJV’s selection of different levels of thrust for different OSV thrusters in the offtake and OSV resupply scenarios is based on marine operational advice. The azipull thrusters (at the stern) are primarily used for propulsion, as opposed to the bow/retractable thrusters which are primarily used for dynamic positioning. During OSV resupply, the propulsion thrusters are typically used less than the dynamic positioning thrusters during OSV resupply. This is different from OSV use during offtake scenarios where the OSV applies force to maintain tension in the offtake arrangement, and therefore the propulsion thrusters are utilised at higher levels.

Thruster locations, diameters, and depths were derived by referring to a technical drawing and cross-referencing this with the known length and breadth of the ship. Monopole source depths Z_s were calculated using the following equation, derived from Gray and Greeley (1980):

$$Z_s = Z_{prop} - 0.85 \cdot \varphi_{prop} \tag{1}$$

where Z_{prop} is the depth at the bottom of the propeller and φ_{prop} is the diameter of the propeller. Thus, depths were calculated as 3.2 m for the AZP100, 6.4 m for the UL1201, and 3.4 m for the CP thrusters.

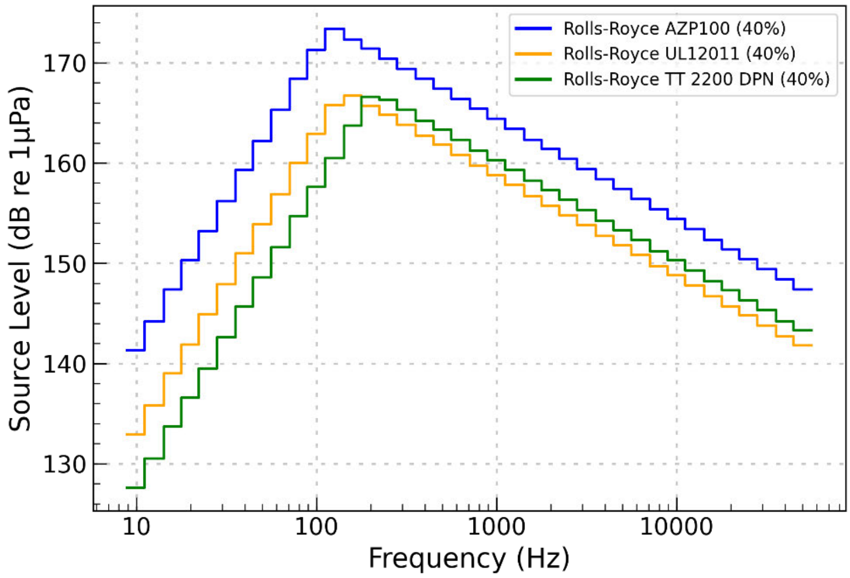

Figure 6. Decidecade band monopole source levels for OSV thruster sources during FPSO offtake. These spectra represent thrusters working at 40% capacity.

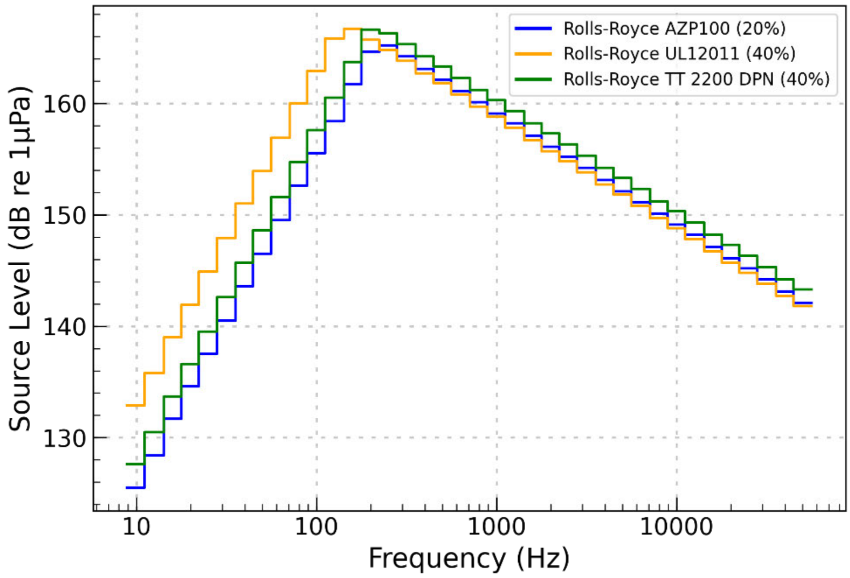

Figure 7. Decidecade band monopole source levels for OSV thruster sources during MODU resupply. These spectra represent thrusters working at 20 and 40% capacity.

3.1.3. Floating Production, Storage, and Offloading (FPSO) Facility

The proposed FPSO facility is a permanently moored, heading controlled production vessel approximately 370 m long and 67 m wide with a draft of 16 m. While in heading control mode, it operates on two stern thrusters positioned laterally on the keel at the stern of the ship 6 m apart.

The major sources of noise from this vessel are the two thrusters and noise associated with pumps, generators, and other machinery within the vessel. As a proxy for the latter noise source, an average of two source levels measured by Erbe et al. (2013) from the FPSO facilities *Nganhurra* and the *Ngujima Yin*, with a broadband source level of 173.9 dB re 1 µPa, was used. The thrusters were modelled as two separate point sources using theoretical source level spectra for 3000 mm nozzled 4 bladed fixed pitch propellers (FPPs), provided by the BJV. These had a broadband source level of 179.5 dB re 1 µPa.

In combination, the machinery noise and two thruster sources reach a broadband source level of 183 dB re 1 µPa. A future design target for the FPSO is a broadband source level of 178 dB re 1 µPa. Given the input spectra, it was calculated that a broadband reduction of 6.6 dB per thruster would be required to reach this target. An offset of −6.6 dB was therefore applied to the thruster spectrum for this additional hypothetical scenario. Figure 8 shows the source spectra for machinery and thrusters with and without the level reduction applied. It can be seen that a broadband reduction of thruster level would have greatest impact in terms of exceeding the machinery noise at frequencies of 80 Hz and above.

Machinery noise was modelled as a point source at the planar centre of the vessel at a depth of 8 m, which is 50% of the draught, consistent with the approach taken in McPherson et al. (2019). The thrusters were modelled as two separate point sources positioned 6 m apart at the stern of the ship (relative to the position of the machinery source) at a depth of 16.5 m, specified by the BJV. Thruster sources were not enabled for the FPSO offtake scenarios.

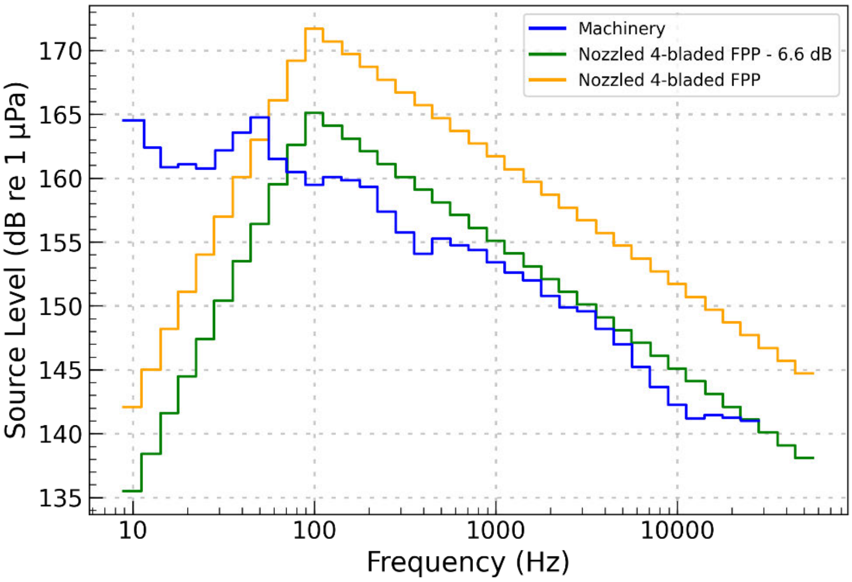

Figure 8. Source levels used for FPSO facility

3.2. Modelling Sound Propagation

JASCO's combined Marine Operations Noise Model (MONM) and gaussian beam acoustic ray-trace model (BELLHOP) were used to predict the acoustic field at frequencies from 10 Hz to 63 kHz. Details on these models are included in Appendix B.1.

Accumulated SEL was calculated using the following equation:

$$L_{E,24h} = L_E + 10\log_{10}(T) \tag{2}$$

where L_E is the per-second energy source level (output by MONM-BELLHOP) and T is the total number of operational seconds in a 24-hour period.

In the modelled scenarios, the FPSO at Torosa, the FPSO offtake activities, and the MODU (either under DP or moored) are considered to be in continuous operation, whilst the OSV during resupply operations at the TRA and TRD drill centres is modelled in operation for both 6 and 12 hours (see Table 9). Using Equation 2, Constant operation over 24 hours yields an offset of 49.3 dB, whilst for 12 hours this is 46.4 dB, and for 6 hours 43.3 dB. These offsets were applied to the relevant calculated received levels.

4. Results

Sound field results for all scenarios are presented in this section as tables and maps showing propagation ranges and isopleths with relevant effect thresholds. These are organised to show SPL results (Tables 13–16, Figures 9–19), followed by SEL results (Tables 17–19, Figures 20–34). The results for the aggregate scenario (Scenario 9, Table 9) are provided in Tables 20–22 and Figures 35–36.

A table entry showing <0.05 indicates a case where a particular noise level has been exceeded in the modelling, but at a range shorter than the minimum grid interpolation distance of 50 m. Figures are presented for each vessel in isolation, as well as offtake and resupply scenarios involving aggregation of noise from multiple vessels.

4.1. Tables

Table 13. *TRA/TRD drill centres, SPL*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (in km) to various SPL levels from the centroids of the vessels involved.

SPL (L_p; dB re 1 µPa)	MODU (under DP)		MODU (Moored)		OSV		MODU Resupply	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
TRA Drill centre								
180	—	—	—	—	—	—	—	—
170	<0.05	<0.05	—	—	<0.05	<0.05	<0.05	<0.05
160	<0.05	<0.05	—	—	<0.05	<0.05	<0.05	<0.05
150	0.08	0.08	—	—	0.06	0.06	0.07	0.07
140	0.22	0.22	<0.05	<0.05	0.17	0.16	0.27	0.26
130	0.69	0.67	0.15	0.15	0.53	0.51	0.96	0.91
120[a]	4.49	2.87	0.49	0.47	2.21	2.10	4.95	3.79
110	13.82	12.39	2.28	2.18	10.89	6.78	17.06	12.96
TRD Drill centre								
180	—	—	—	—	—	—	—	—
170	<0.05	<0.05	—	—	<0.05	<0.05	<0.05	<0.05
160	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
150	0.09	0.09	<0.05	<0.05	0.06	0.06	0.09	0.07
140	0.22	0.22	<0.05	<0.05	0.17	0.16	0.26	0.25
130	0.69	0.67	0.15	0.15	0.54	0.51	1.11	0.99
120[a]	4.10	2.73	0.49	0.47	3.14	2.04	5.49	3.66
110	12.97	11.24	2.25	2.13	10.36	6.12	16.49	11.65

[a] Threshold for marine mammal behavioural response to continuous noise (NOAA 2019).
A dash indicates the level was not reached.

Table 14. *Torosa FPSO location, SPL*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (in km) to various SPL levels from the centroids of the vessels involved.

SPL (L_p; dB re 1 µPa)	FPSO, Heading Control		FPSO, Heading Control (Optimised Thrusters)		FPSO Offtake	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
180	—	—	—	—	—	—
170	<0.05	<0.05	—	—	<0.05	<0.05
160	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
150	0.06	0.06	<0.05	<0.05	0.07	0.07
140	0.21	0.19	0.09	0.08	0.25	0.24
130	0.66	0.63	0.34	0.32	0.99	0.94
120[a]	2.82	2.66	1.67	1.55	2.67	2.49
110	13.05	9.78	5.65	5.19	9.45	8.14

[a] Threshold for marine mammal behavioural response to continuous noise (NOAA 2019).

FPSO offtake includes an FPSO, a noiseless condensate tanker and an OSV.

A dash indicates the level was not reached.

Table 15. *TRA/TRD drill centres, SPL, fish effect thresholds*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (km) from the vessels to modelled maximum-over-depth SPL thresholds based on the quantifiable thresholds for fish with a swim bladder involved in hearing (Popper et al. 2014).

SPL (L_p; dB re 1 µPa)	MODU (under DP)		MODU (Moored)		OSV		MODU Resupply	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
TRA Drill centre								
170[a]	<0.05	<0.05	—	—	<0.05	<0.05	<0.05	<0.05
158[b]	<0.05	<0.05	—	—	<0.05	<0.05	<0.05	<0.05
TRD Drill centre								
170[a]	0.06	0.06	—	—	<0.05	<0.05	<0.05	<0.05
158[b]	0.06	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

[a] Recoverable injury (Popper et al. 2014)

[b] TTS

Table 16. *Torosa FPSO location, SPL, fish effect thresholds*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (km) from the vessels to modelled maximum-over-depth SPL thresholds based on the quantifiable thresholds for fish with a swim bladder involved in hearing (Popper et al. 2014).

SPL (L_p; dB re 1 µPa)	FPSO, Heading Control		FPSO, Heading Control (Optimised Thrusters)		FPSO Offtake	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
170[a]	<0.05	<0.05	—	—	<0.05	<0.05
158[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

[a] Recoverable injury (Popper et al. 2014)

[b] TTS

FPSO offtake includes an FPSO, a noiseless condensate tanker and an OSV.

A dash indicates the level was not reached.

Table 17. *TRA drill centre, SEL_{24h}*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (km) from the vessels to modelled maximum-over-depth PTS and TTS thresholds for marine mammals (NMFS 2018) and sea turtles (Finneran et al. 2017).

Hearing group	Threshold for SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²s)[a]	MODU (under DP)		MODU (Moored)		OSV (6 h)		OSV (12 h)		MODU Resupply (OSV 6 h)		MODU Resupply (OSV 12 h)	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
PTS													
LF cetaceans	199	<0.05	<0.05	—	—	<0.05	<0.05	0.06	0.06	0.06	0.06	0.06	0.06
MF cetaceans	198	<0.05	<0.05	—	—	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
HF cetaceans	173	0.09	0.09	<0.05	<0.05	0.06	0.06	0.07	0.07	0.09	0.09	0.10	0.09
Sea turtles	220	<0.05	<0.05	—	—	—	—	—	—	<0.05	<0.05	<0.05	<0.05
TTS													
LF cetaceans	179	0.51	0.50	0.12	0.12	0.24	0.23	0.35	0.33	0.55	0.52	0.58	0.55
MF cetaceans	178	0.08	0.08	—	—	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07
HF cetaceans	153	0.77	0.75	0.30	0.29	0.43	0.42	0.66	0.64	0.89	0.86	1.02	0.98
Sea turtles	200	<0.05	<0.05	—	—	<0.05	<0.05	0.06	0.06	0.06	0.06	0.06	0.06

[a] Frequency weighted.

A dash indicates the level was not reached.

Table 18. *TRD drill centre, SEL$_{24h}$*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (km) from the vessels to modelled maximum-over-depth PTS and TTS thresholds for marine mammals (NMFS 2018) and sea turtles (Finneran et al. 2017).

Hearing group	Threshold for SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa²s)[a]	MODU (under DP)		MODU (Moored)		OSV (6 h)		OSV (12 h)		MODU Resupply (OSV 6 h)		MODU Resupply (OSV 12 h)	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
PTS													
LF cetaceans	199	0.06	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MF cetaceans	198	0.06	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
HF cetaceans	173	0.09	0.09	<0.05	<0.05	<0.05	<0.05	0.06	0.06	0.10	0.09	0.10	0.09
Sea turtles	220	0.06	0.06	—	—	—	—	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
TTS													
LF cetaceans	179	0.51	0.50	0.13	0.13	0.25	0.24	0.35	0.33	0.54	0.51	0.58	0.55
MF cetaceans	178	0.07	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	0.07	0.07	0.07
HF cetaceans	153	0.77	0.75	0.30	0.29	0.43	0.42	0.66	0.63	0.90	0.86	1.02	0.98
Sea turtles	200	0.07	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

[a] Frequency weighted.

A dash indicates the level was not reached.

Table 19. *Torosa FPSO location, SEL$_{24h}$*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (km) from the vessels to modelled maximum-over-depth PTS and TTS thresholds for marine mammals (NMFS 2018) and sea turtles (Finneran et al. 2017).

Hearing group	Threshold for SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa²s)[a]	FPSO, Heading Control		FPSO, Heading Control (Optimised Thrusters)		FPSO Offtake	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
PTS							
LF cetaceans	199	<0.05	<0.05	<0.05	<0.05	0.07	0.07
MF cetaceans	198	<0.05	<0.05	—	—	<0.05	<0.05
HF cetaceans	173	0.06	0.06	<0.05	<0.05	0.11	0.10
Sea turtles	220	—	—	—	—	<0.05	<0.05
TTS							
LF cetaceans	179	0.46	0.43	0.22	0.21	0.63	0.60
MF cetaceans	178	<0.05	<0.05	<0.05	<0.05	0.07	0.07
HF cetaceans	153	0.66	0.63	0.34	0.32	1.24	1.18
Sea turtles	200	<0.05	<0.05	<0.05	<0.05	0.06	0.06

[a] Frequency weighted.

A dash indicates the level was not reached.

4.1.1. Aggregate Scenario

Table 20. *Torosa FPSO location and TRD drill centre, Aggregate FPSO offtake and MODU under DP, SPL*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (in km) to various SPL levels from the centroids of the vessels involved.

SPL (L_p; dB re 1 µPa)	R_{max} (km)	$R_{95\%}$ (km)
180	—	—
170	<0.05	<0.05
160	<0.05	<0.05
150	0.09	0.07
140	0.24	0.22
130	1.00	0.85
120[a]	4.68	2.54
110	15.45	9.78

[a] Threshold for marine mammal behavioural response to continuous noise (NOAA 2019).

A dash indicates the level was not reached.

Table 21. *Torosa FPSO location and TRD drill centre, Aggregate FPSO offtake and MODU under DP, SPL, fish effect thresholds*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (km) from the vessels to modelled maximum-over-depth SPL thresholds based on the quantifiable thresholds for fish with a swim bladder involved in hearing (Popper et al. 2014).

SPL (L_p; dB re 1 µPa)	R_{max} (km)	$R_{95\%}$ (km)
170[a]	<0.05	<0.05
158[b]	<0.05	<0.05

[a] Recoverable injury (Popper et al. 2014)

[b] TTS

FPSO offtake includes an FPSO, a noiseless condensate tanker and an OSV.

Table 22. *Torosa FPSO location and TRD drill centre, Aggregate FPSO offtake and MODU under DP, SEL_{24h}*: Maximum (R_{max}) and 95% ($R_{95\%}$) planar ranges (km) from the vessels to modelled maximum-over-depth PTS and TTS thresholds for marine mammals (NMFS 2018) and sea turtles (Finneran et al. 2017).

Hearing group	Threshold for SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²s)[a]	R_{max} (km)	$R_{95\%}$ (km)
PTS			
LF cetaceans	199	<0.05	<0.05
MF cetaceans	198	<0.05	<0.05
HF cetaceans	173	0.09	0.09
Sea turtles	220	<0.05	<0.05
TTS			
LF cetaceans	179	0.63	0.53
MF cetaceans	178	0.07	0.07
HF cetaceans	153	1.24	1.06
Sea turtles	200	0.07	<0.05

[a] Frequency weighted.

4.2. Maps

4.2.1. Maximum-over-depth SPL Sound Fields

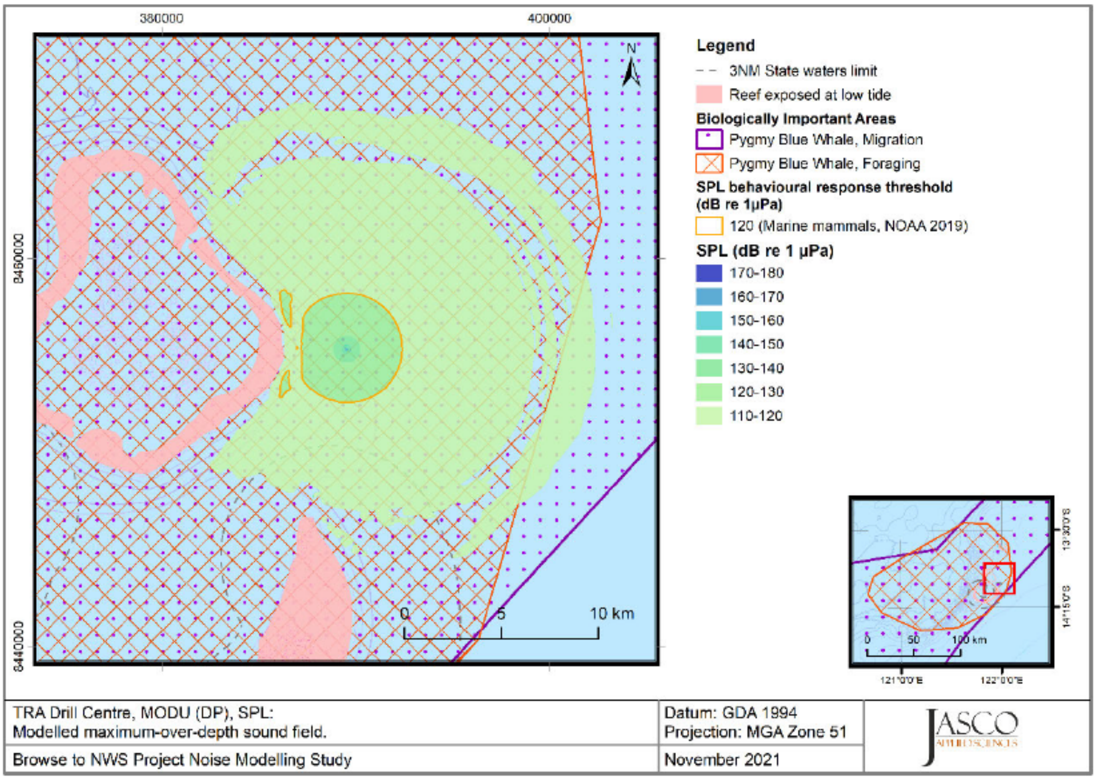

Figure 9. *TRA Drill centre, MODU, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

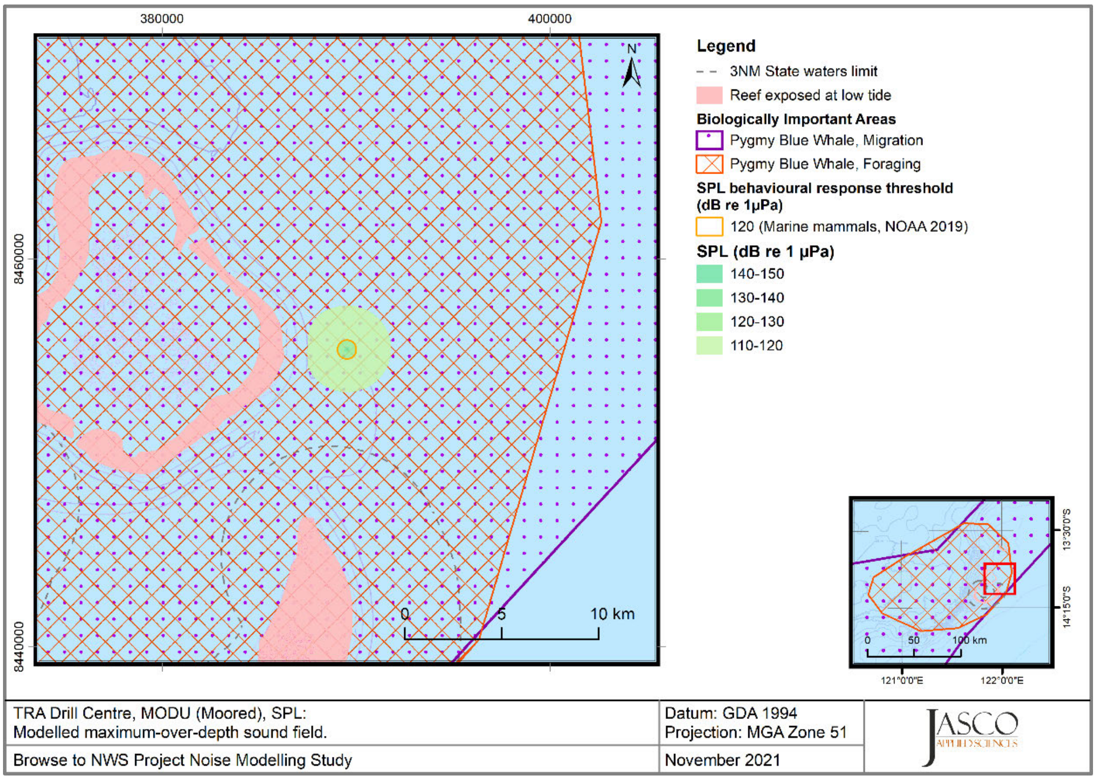

Figure 10. *TRA Drill centre, MODU (Moored), SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

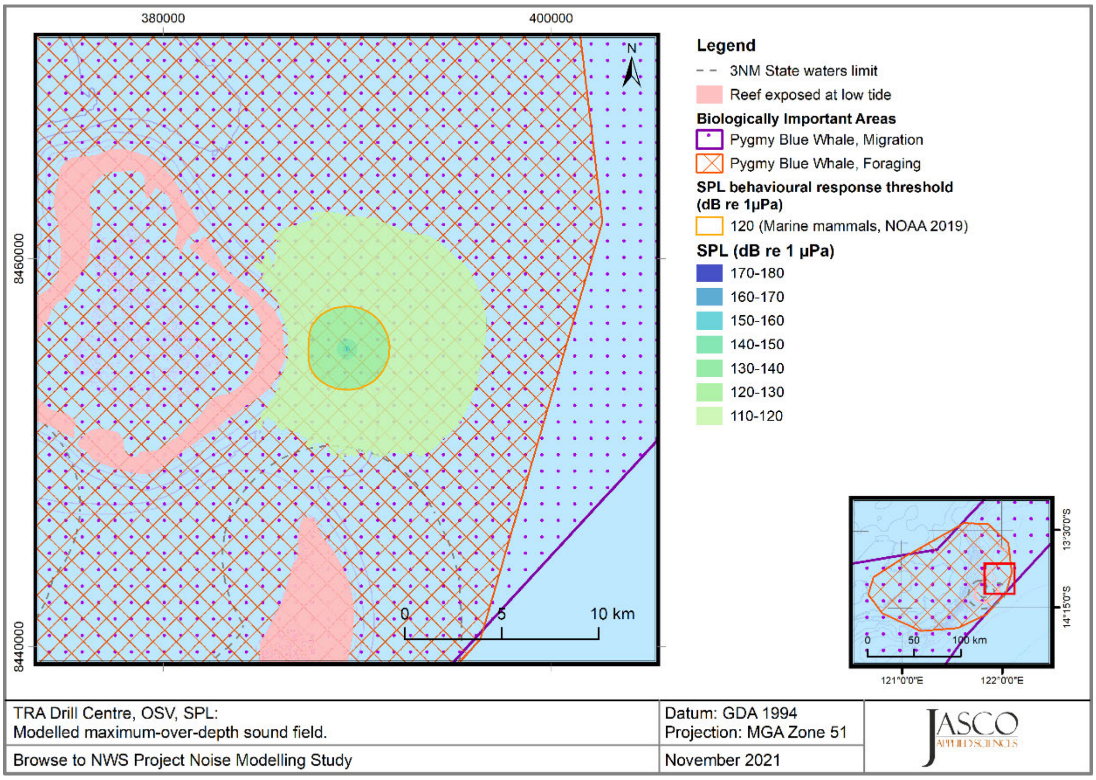

Figure 11. *TRA Drill centre, OSV, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

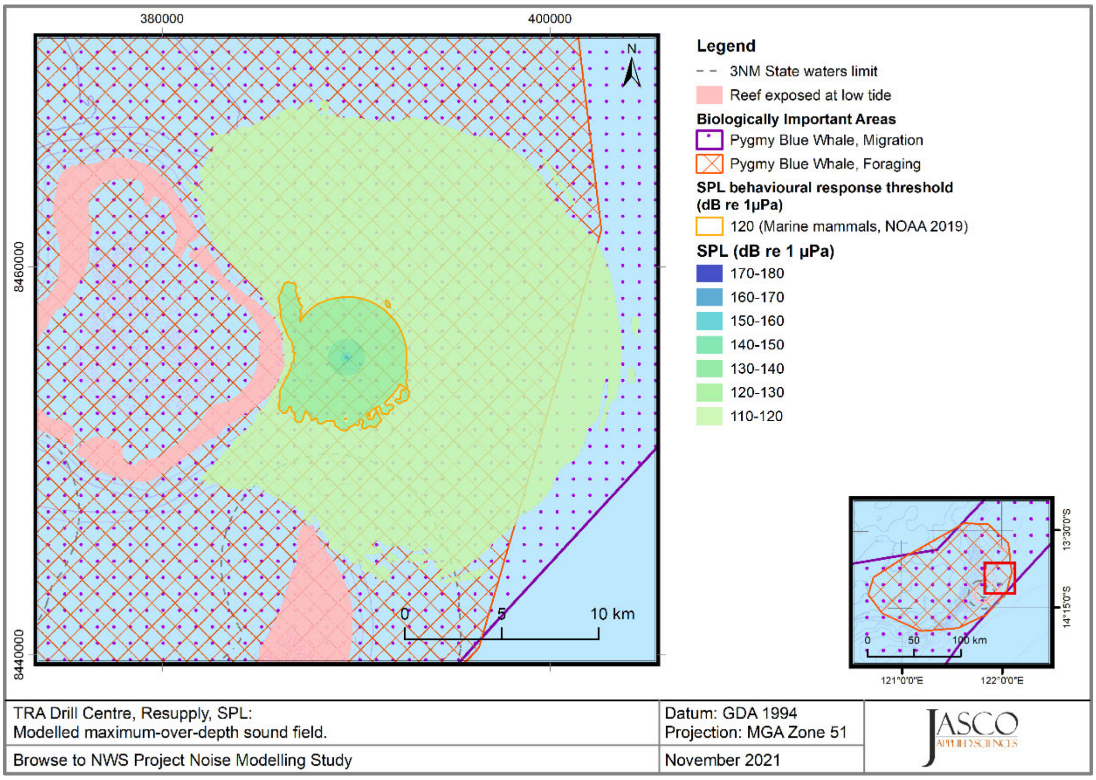

Figure 12. *TRA Drill centre, MODU under DP resupply, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

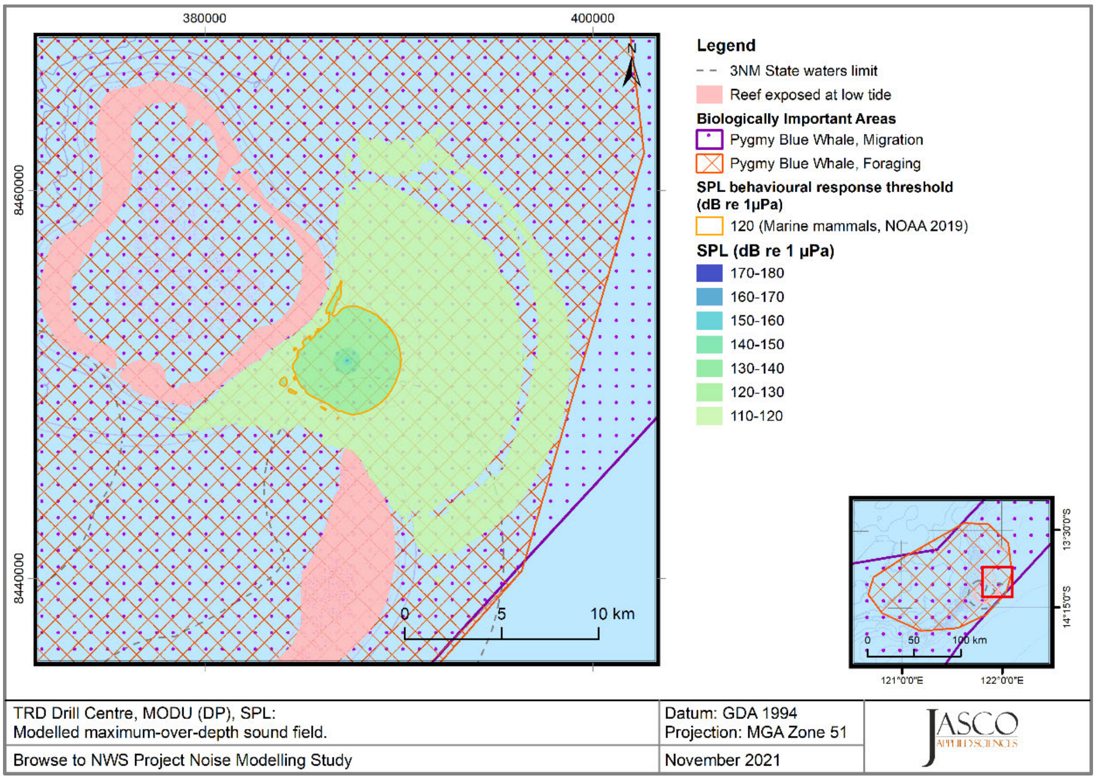

Figure 13. *TRD Drill centre, MODU, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

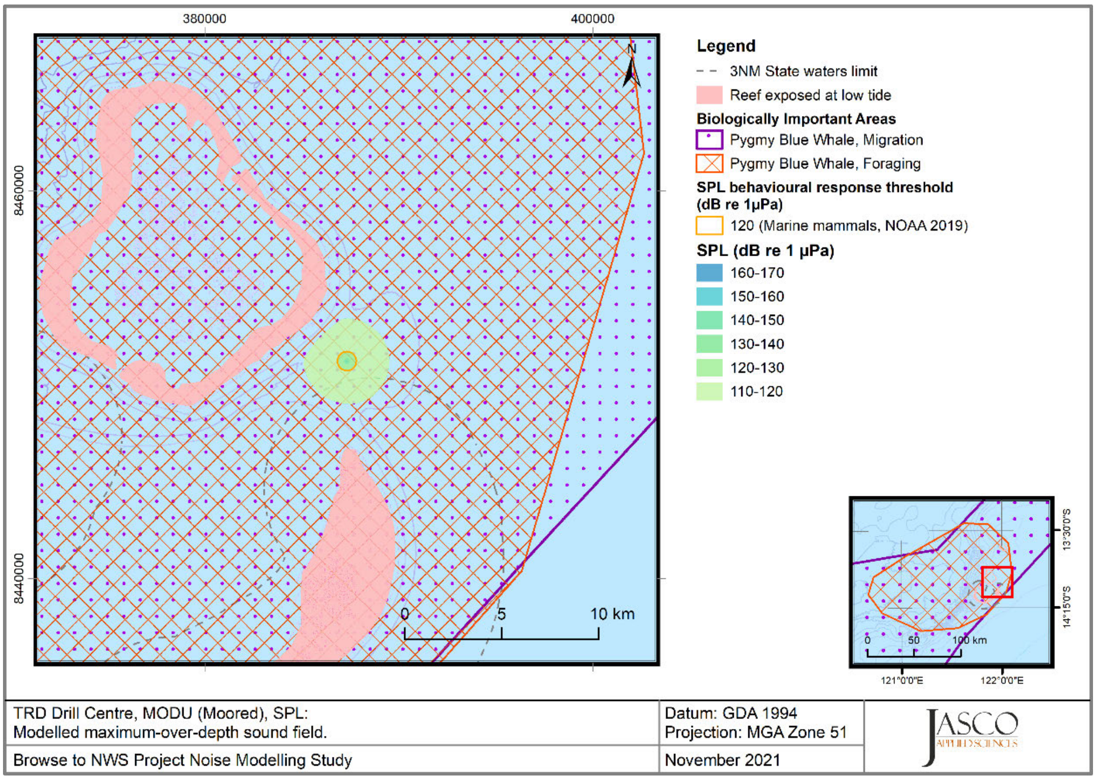

Figure 14. *TRD Drill centre, MODU (Moored), SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

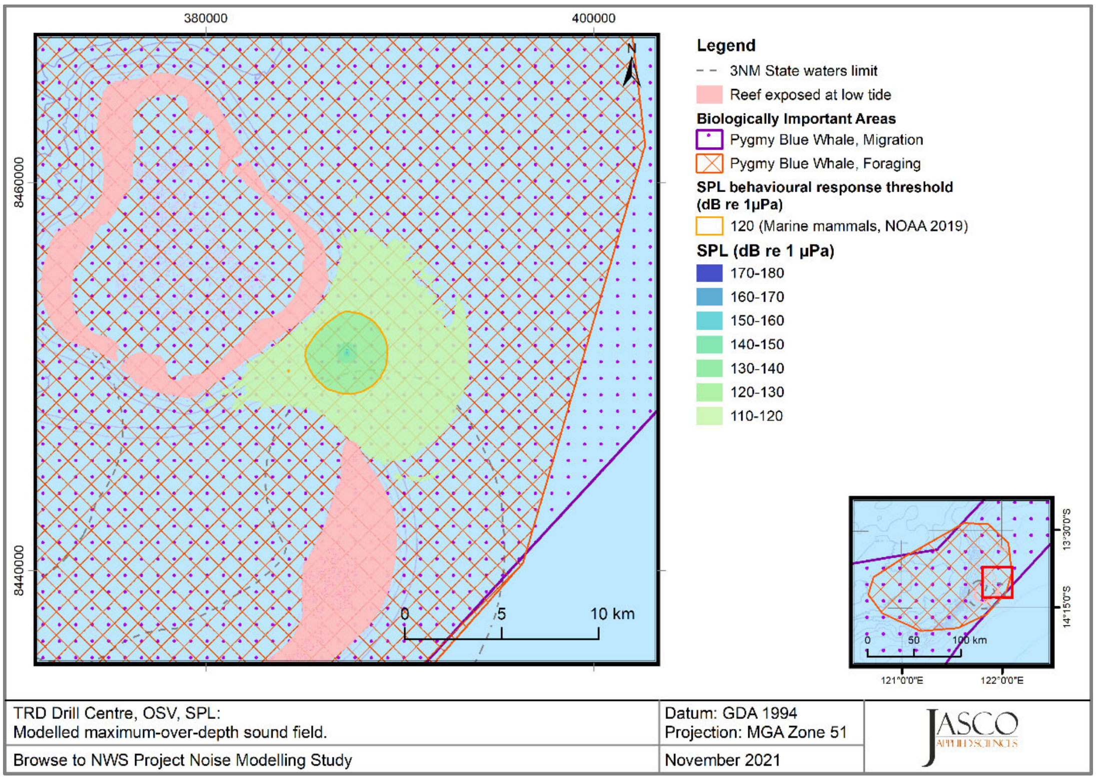

Figure 15. *TRD Drill centre, OSV, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

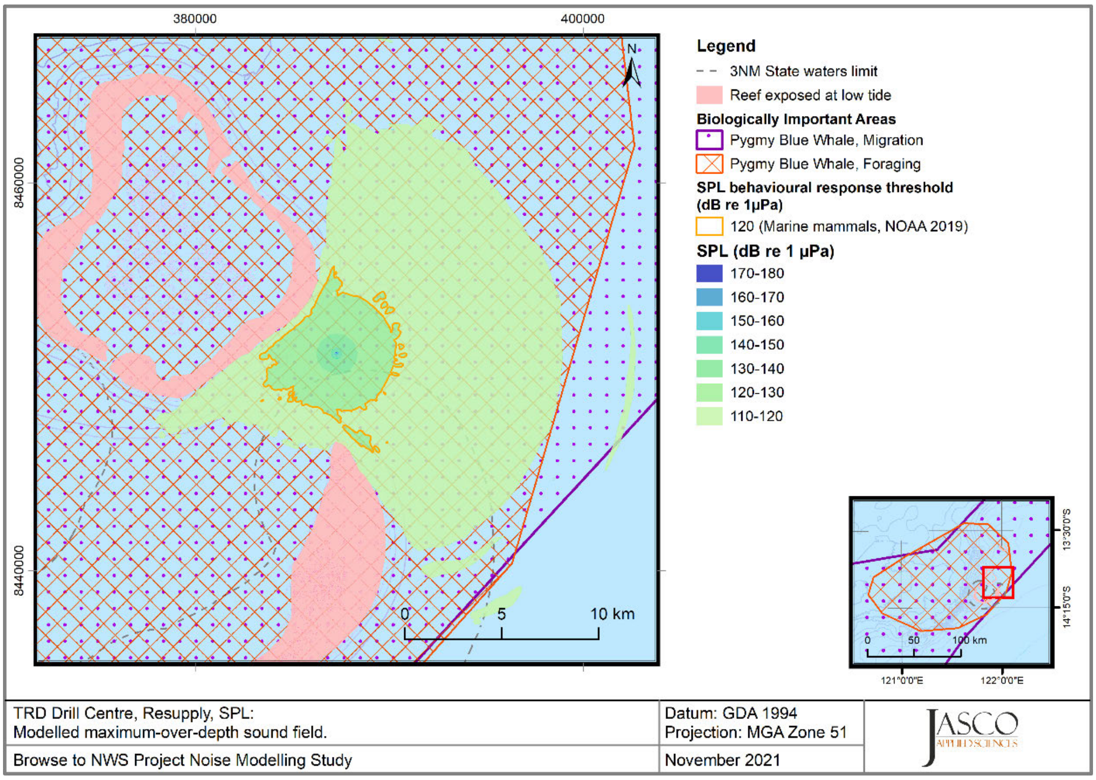

Figure 16. *TRD Drill centre, MODU under DP resupply, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

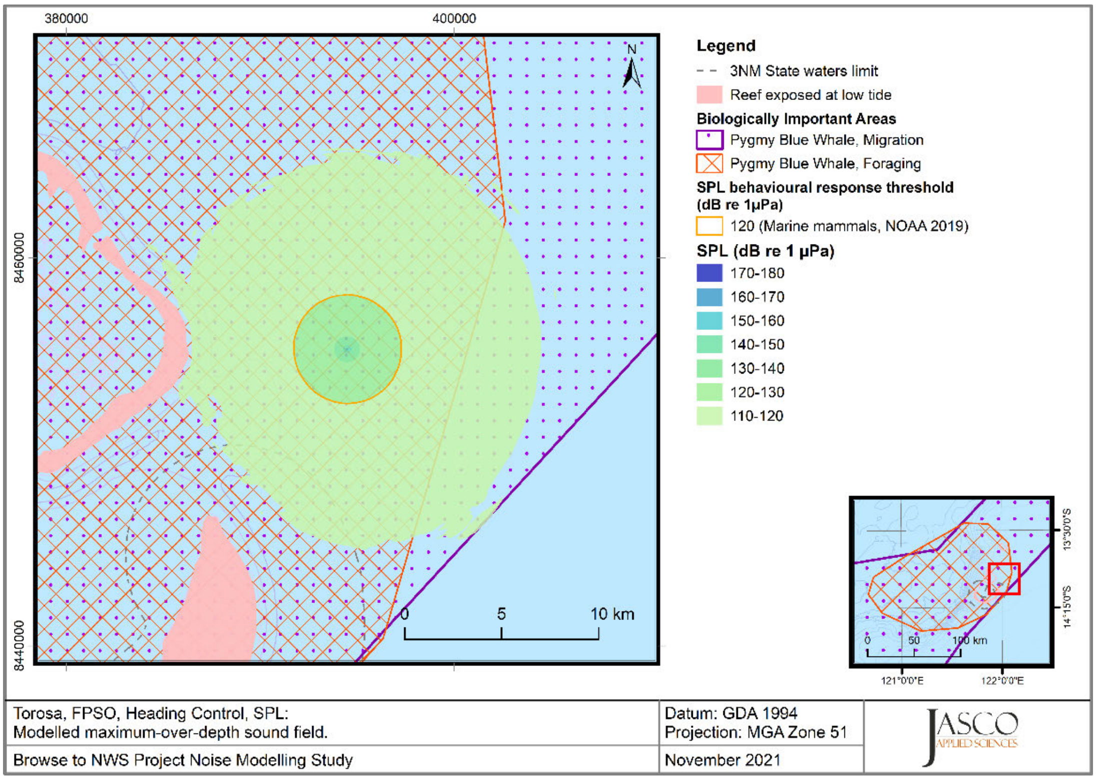

Figure 17. *Torosa location, FPSO, Heading Control, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

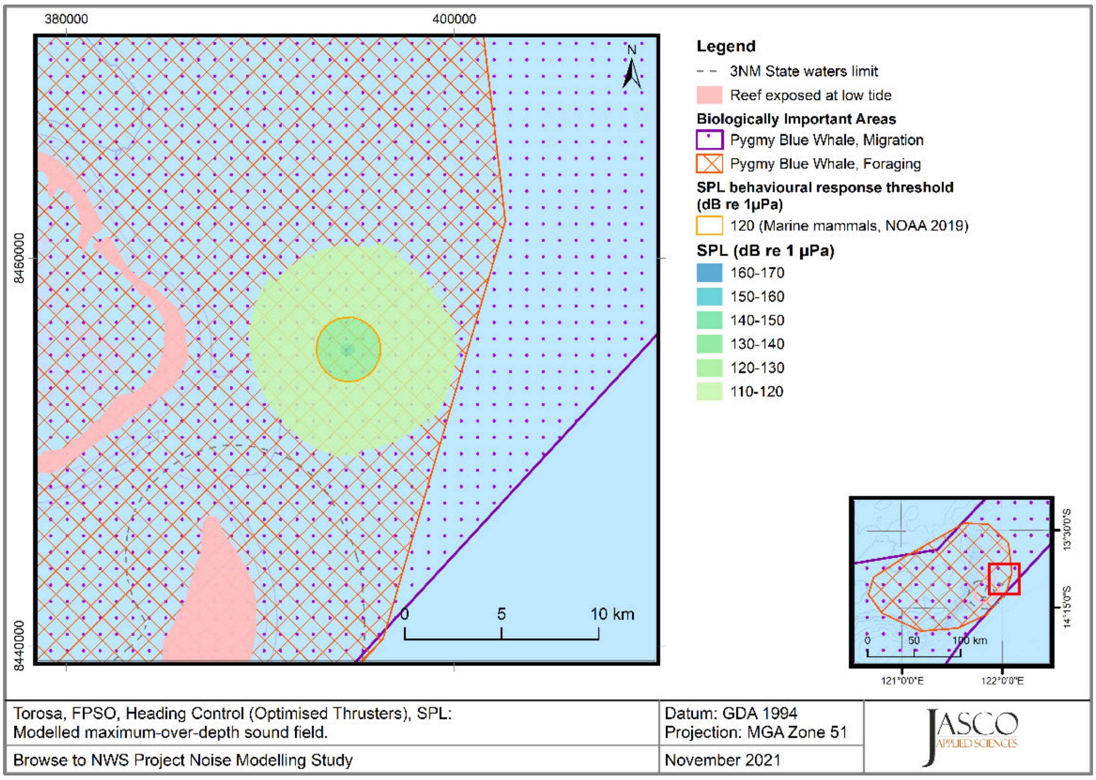

Figure 18. *Torosa, FPSO, Heading Control (Optimised Thrusters), SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

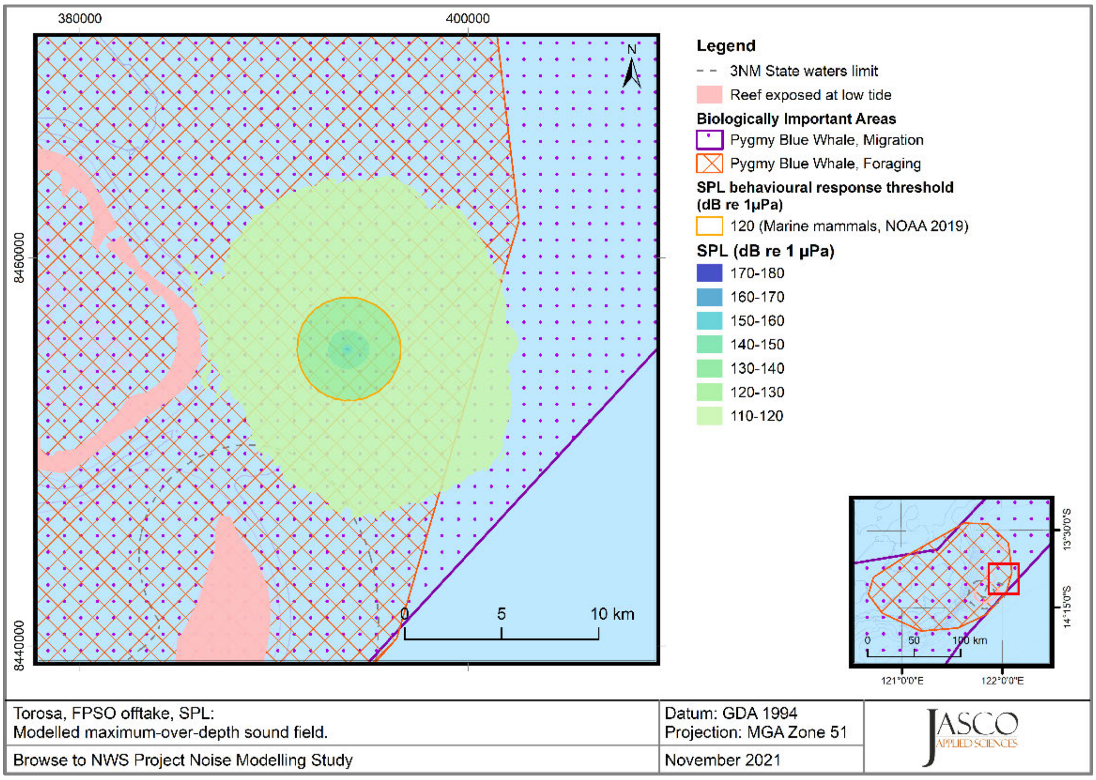

Figure 19. *Torosa location, FPSO Offtake, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

4.2.2. Accumulated SEL Sound Fields

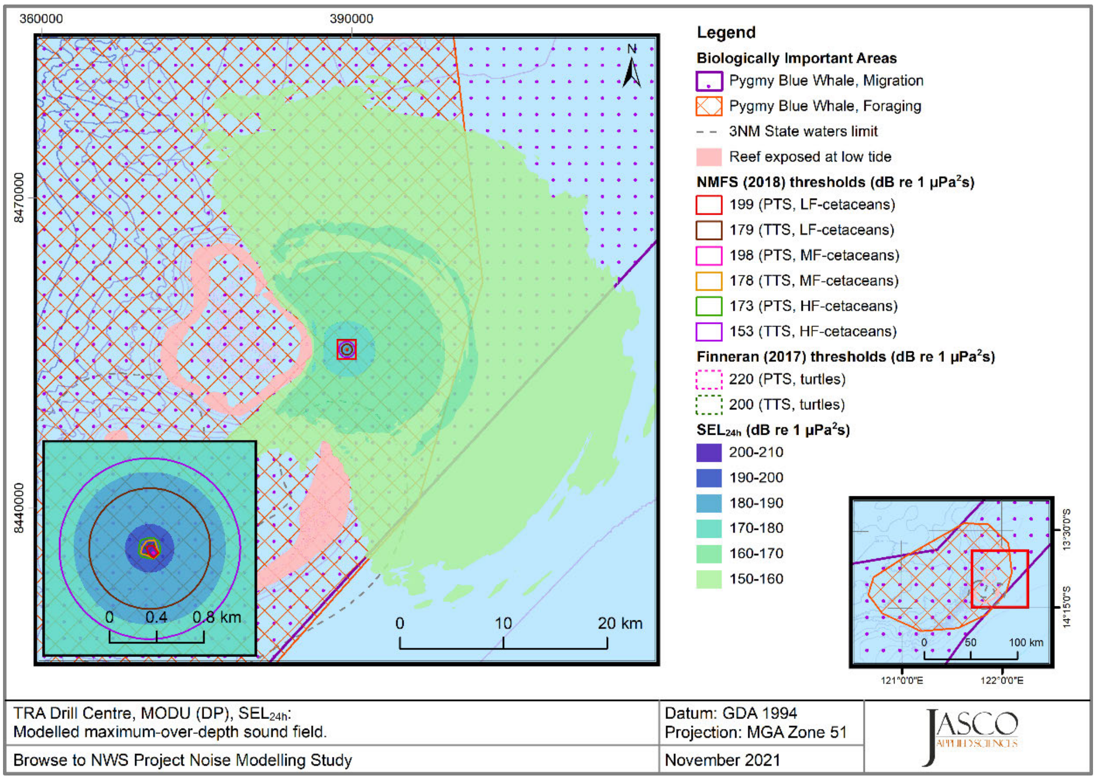

Figure 20. *TRA Drill centre, MODU, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

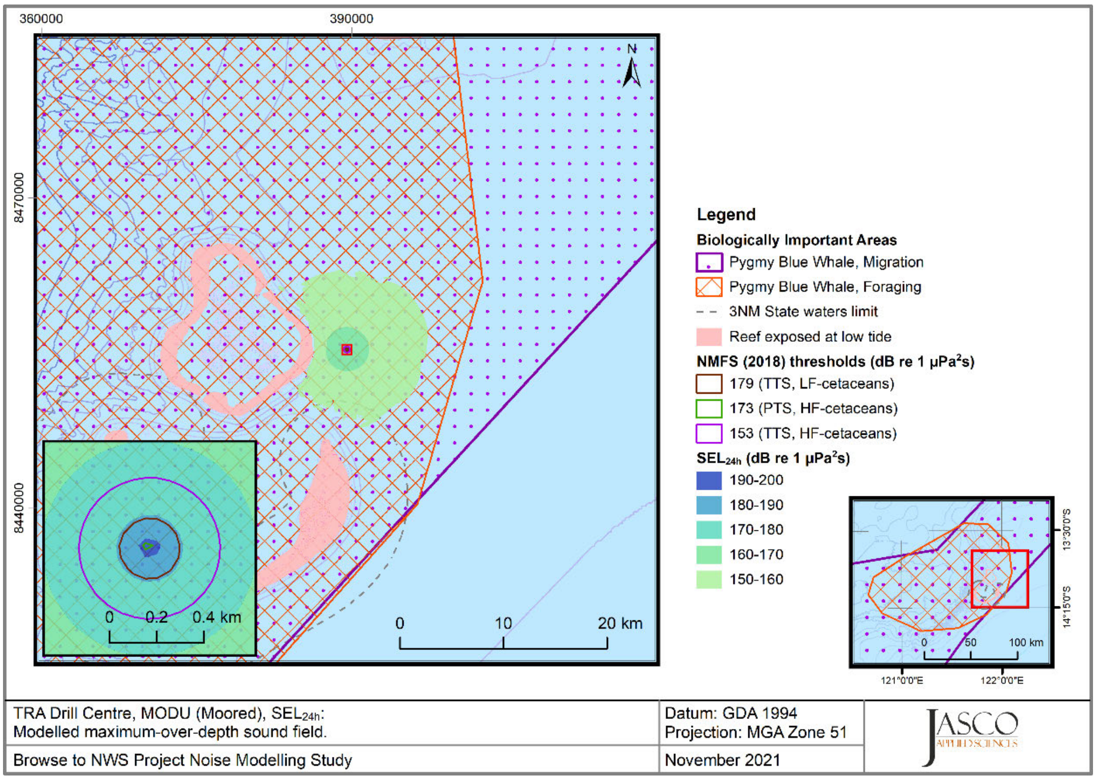

Figure 21. *TRA Drill centre, MODU (Moored), SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{6h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

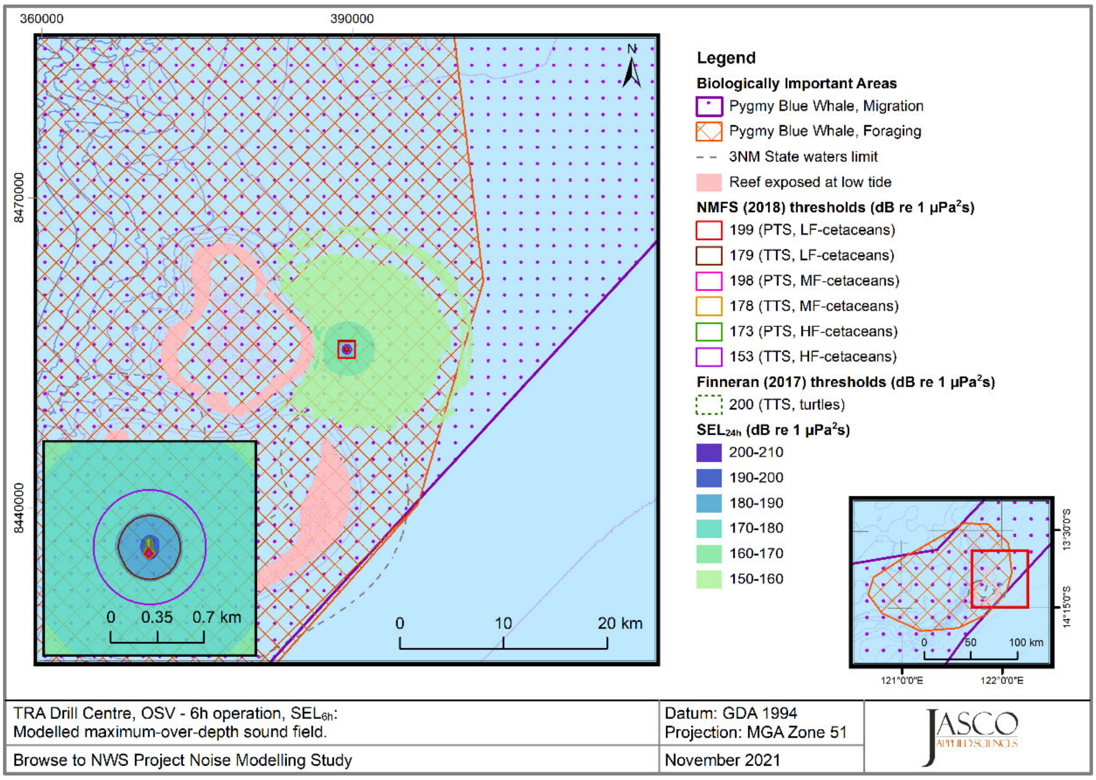

Figure 22. *TRA Drill centre, OSV-6 h operation, SEL$_{6h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{6h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

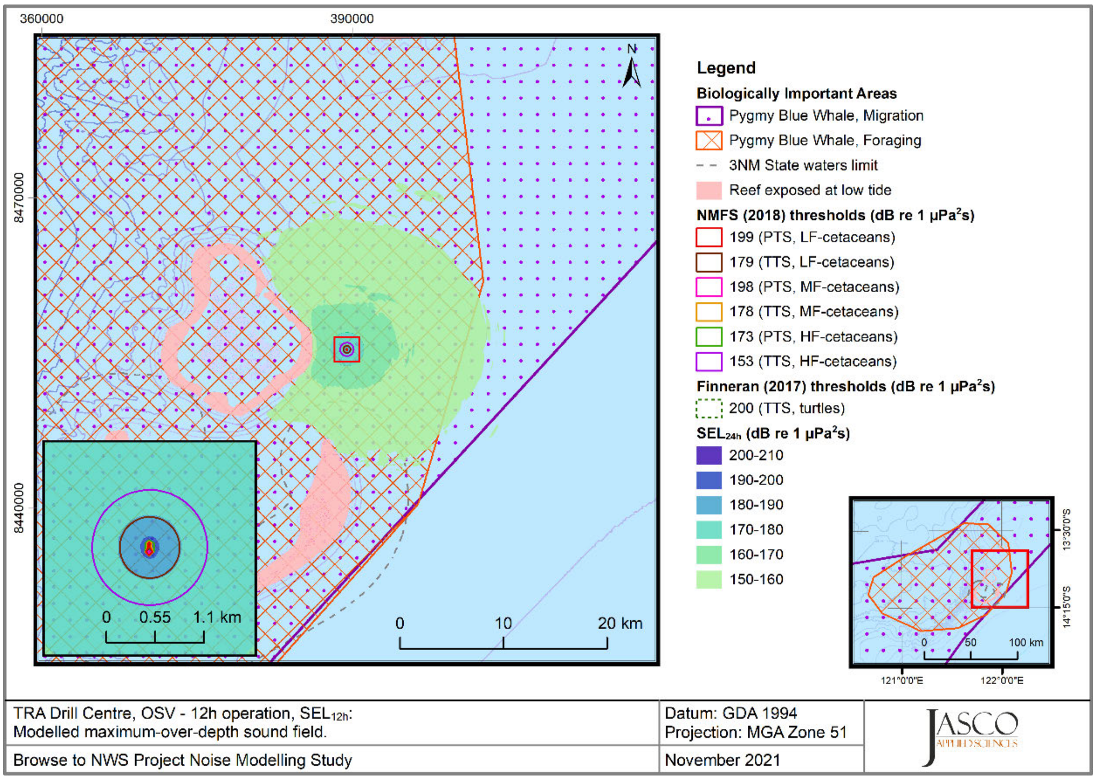

Figure 23. *TRA Drill centre, OSV-12 h operation, SEL$_{12h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{12h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

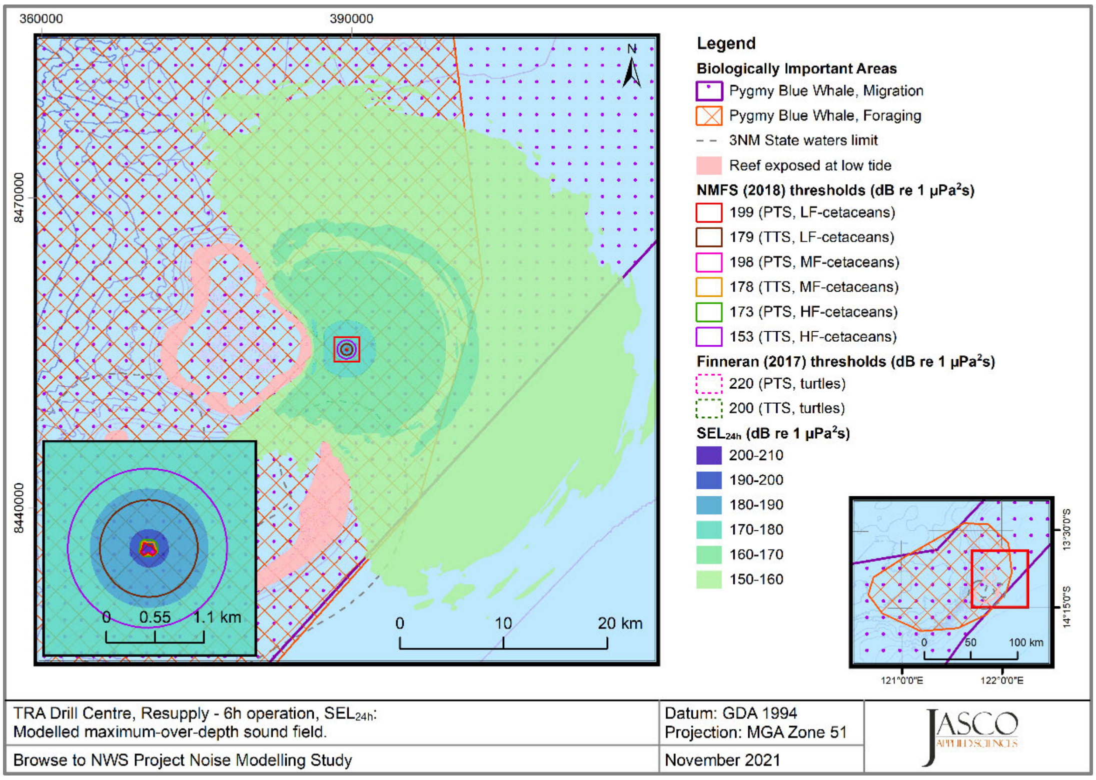

Figure 24. *TRA Drill centre, MODU under DP resupply-6 h operation, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL24h results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

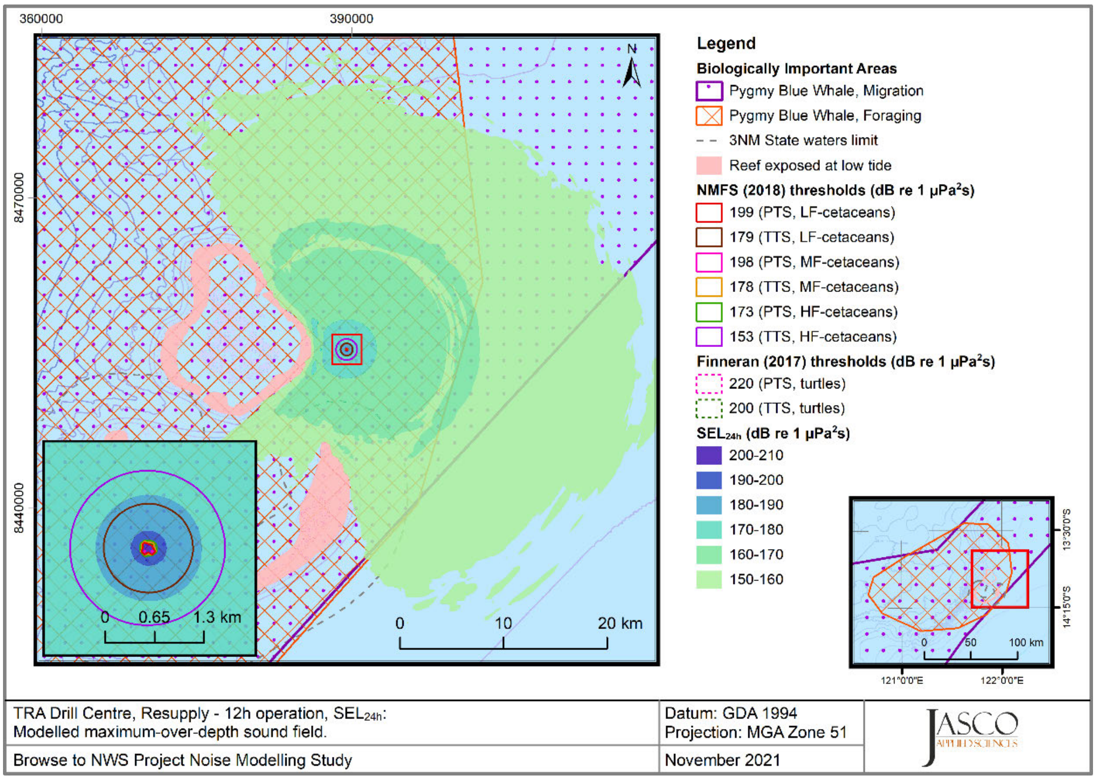

Figure 25. *TRA Drill centre, MODU under DP resupply-12 h operation, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

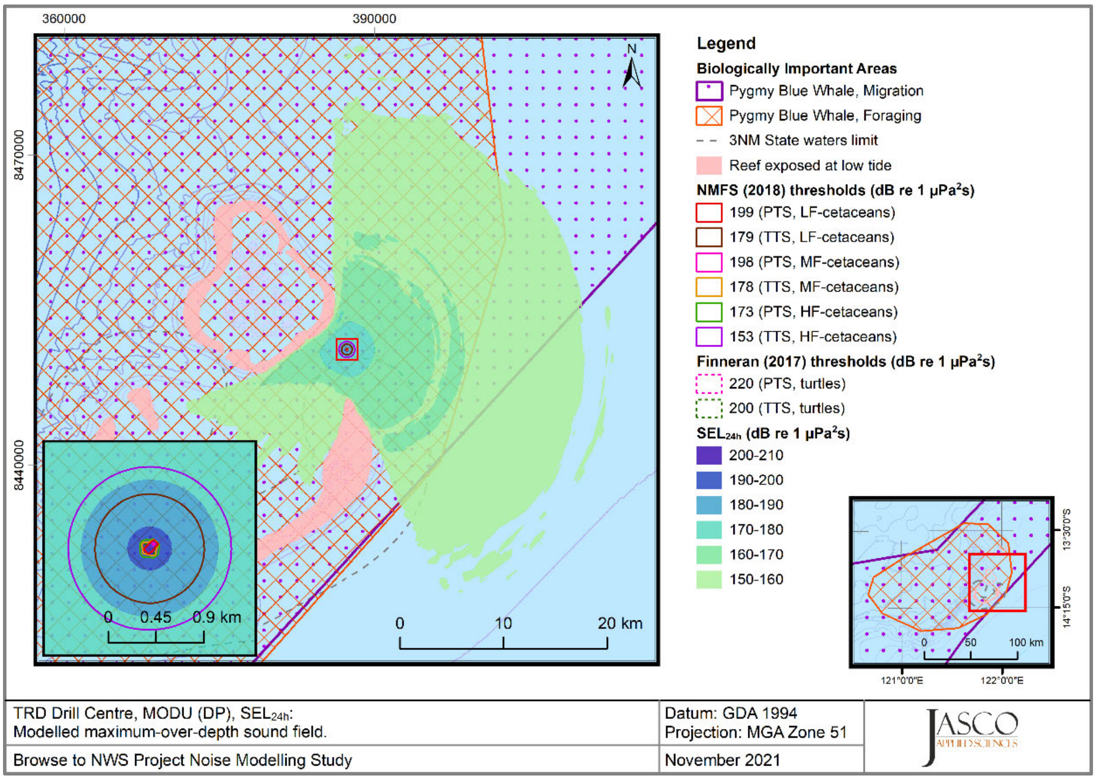

Figure 26. *TRD Drill centre, MODU, SEL_{24h}*: Sound level contour map showing unweighted maximum-over-depth SEL_{24h} results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

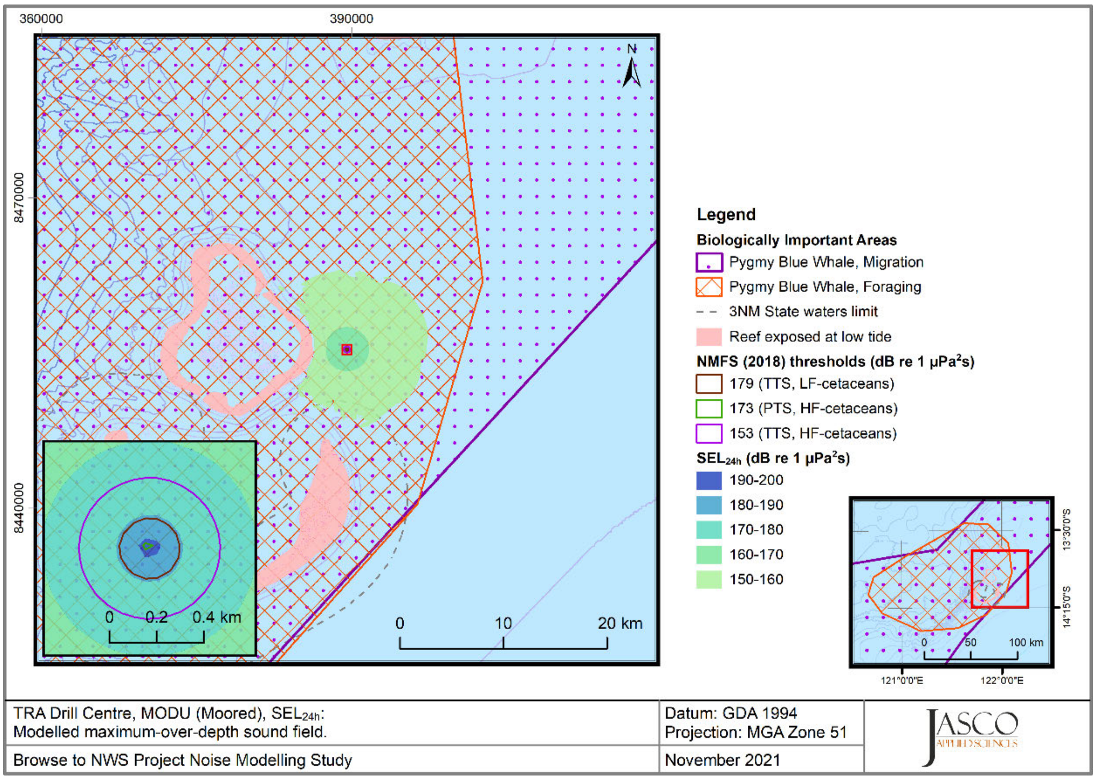

Figure 27. *TRD Drill centre, MODU (Moored), SEL_{24h}*: Sound level contour map showing unweighted maximum-over-depth SEL_{6h} results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

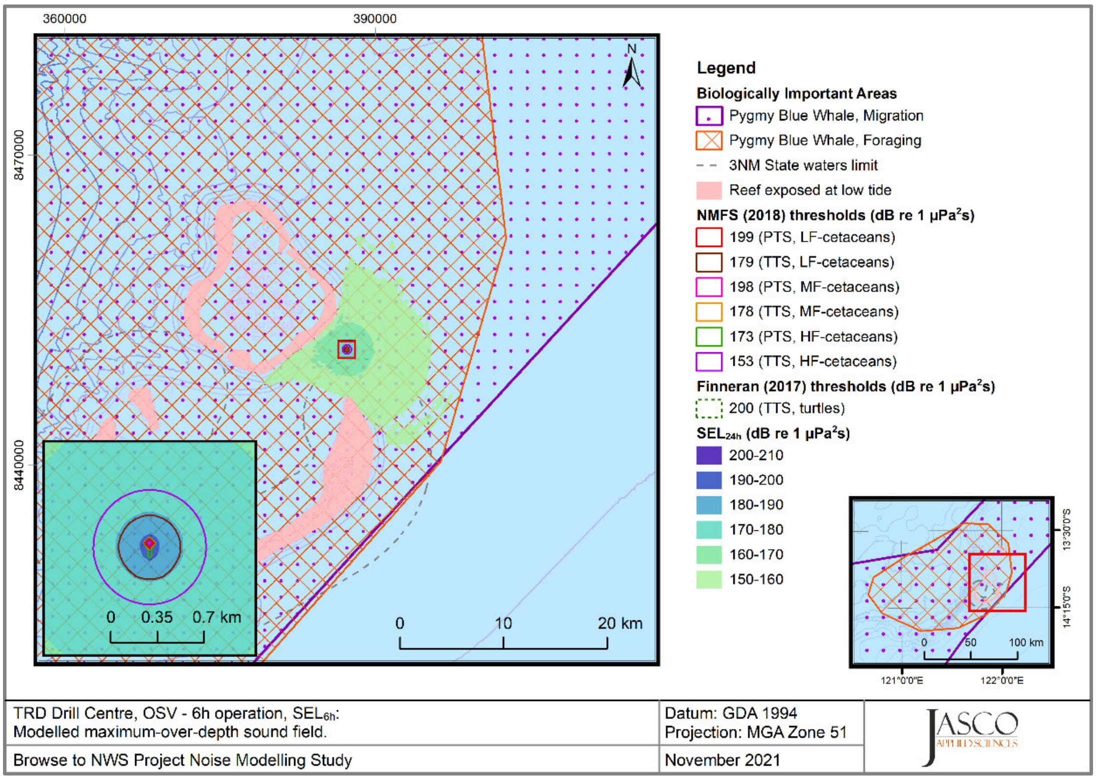

Figure 28. *TRD Drill centre, OSV-6 h operation, SEL$_{6h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{6h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

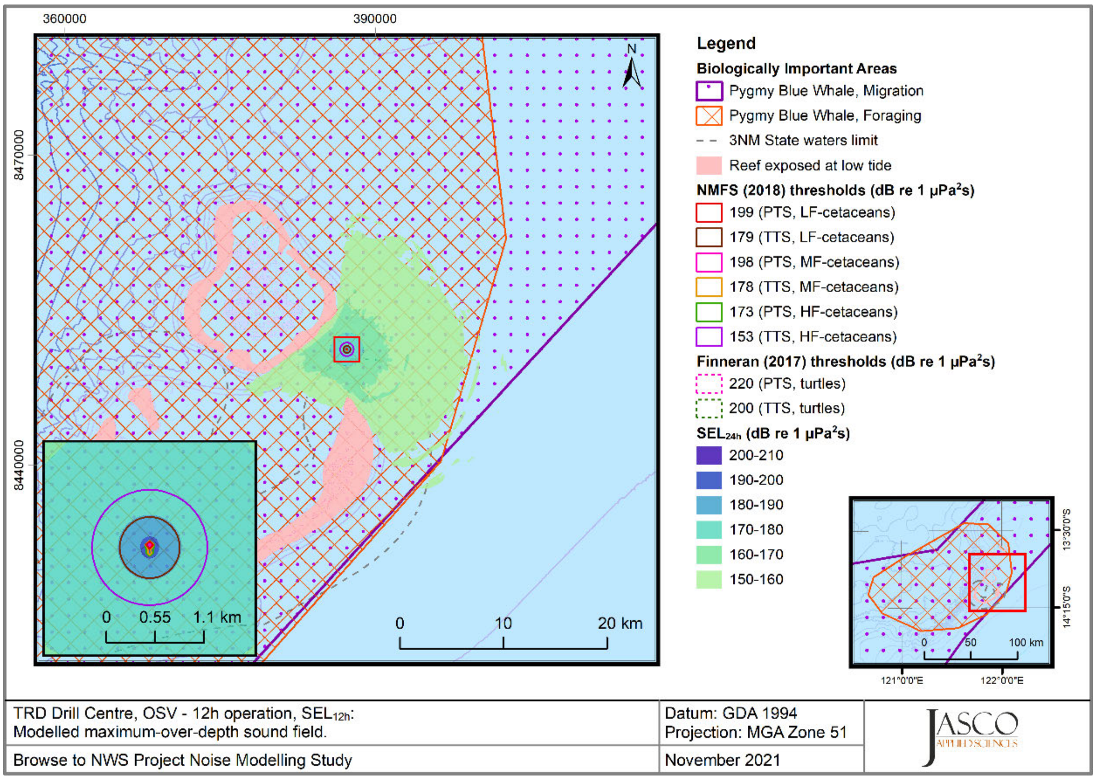

Figure 29. *TRD Drill centre, OSV-12 h operation, SEL$_{12h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{12h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

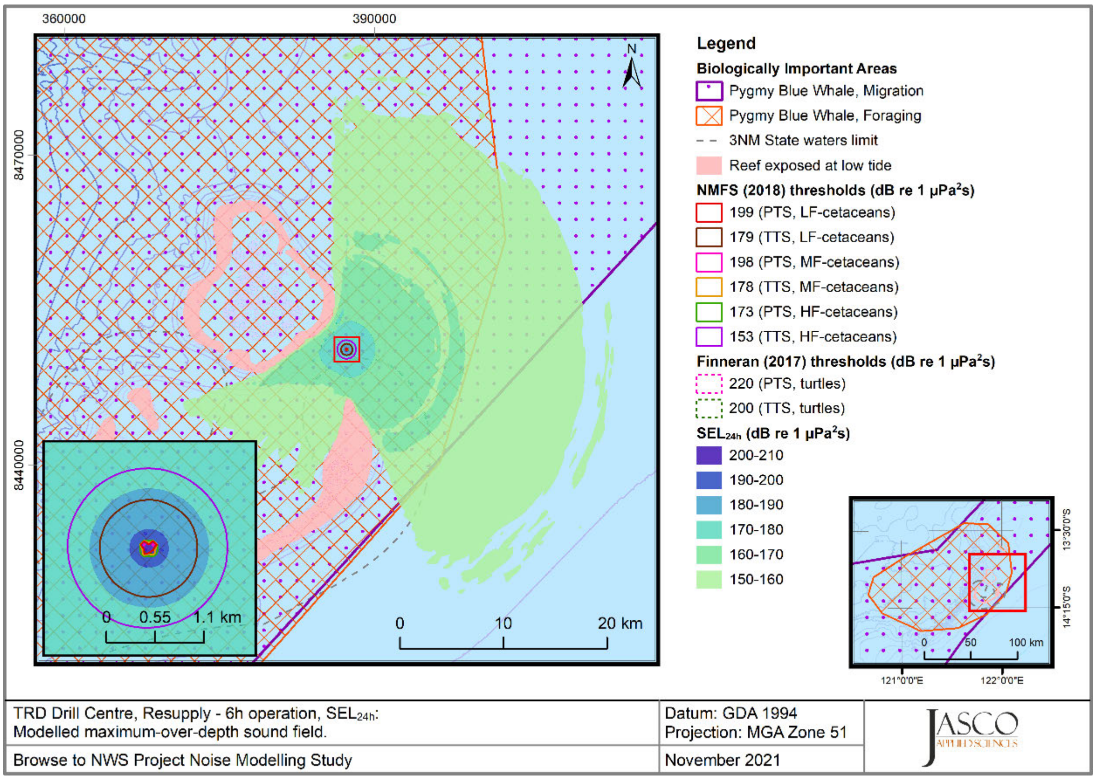

Figure 30. *TRD Drill centre, MODU under DP resupply-6 h operation, SEL_{24h}*: Sound level contour map showing unweighted maximum-over-depth SEL_{24h} results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

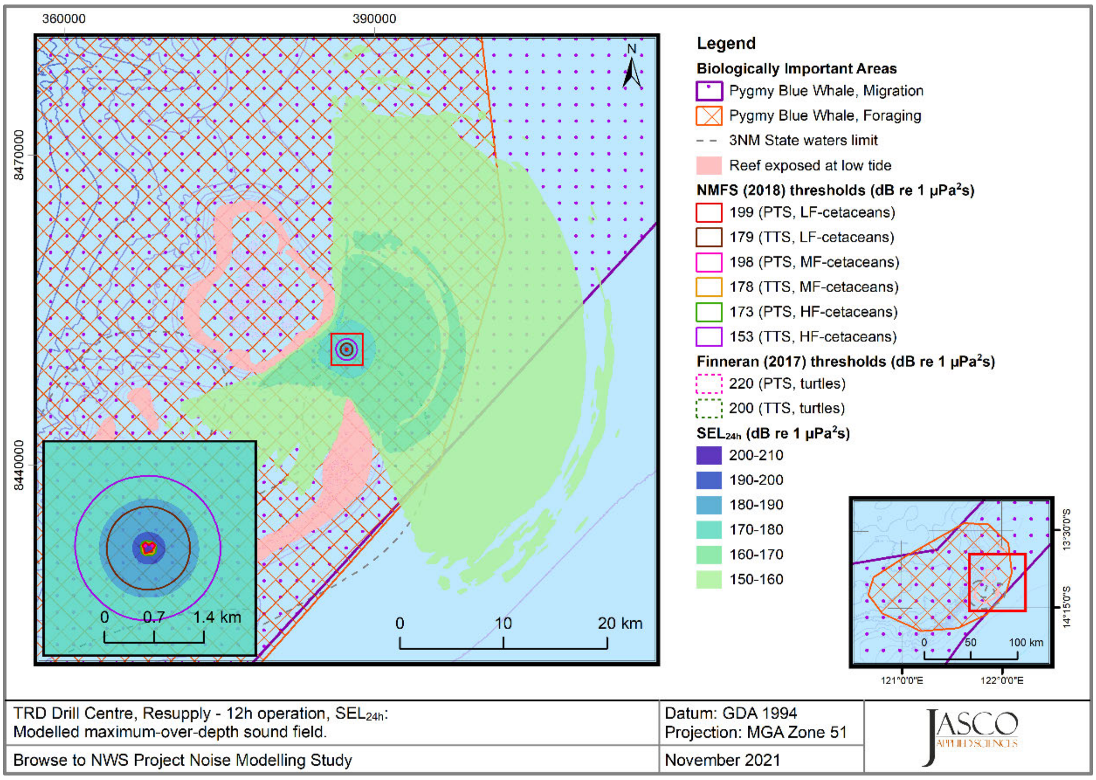

Figure 31. *TRD Drill centre, MODU under DP resupply-12 h operation, SEL_{24h}*: Sound level contour map showing unweighted maximum-over-depth SEL_{24h} results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

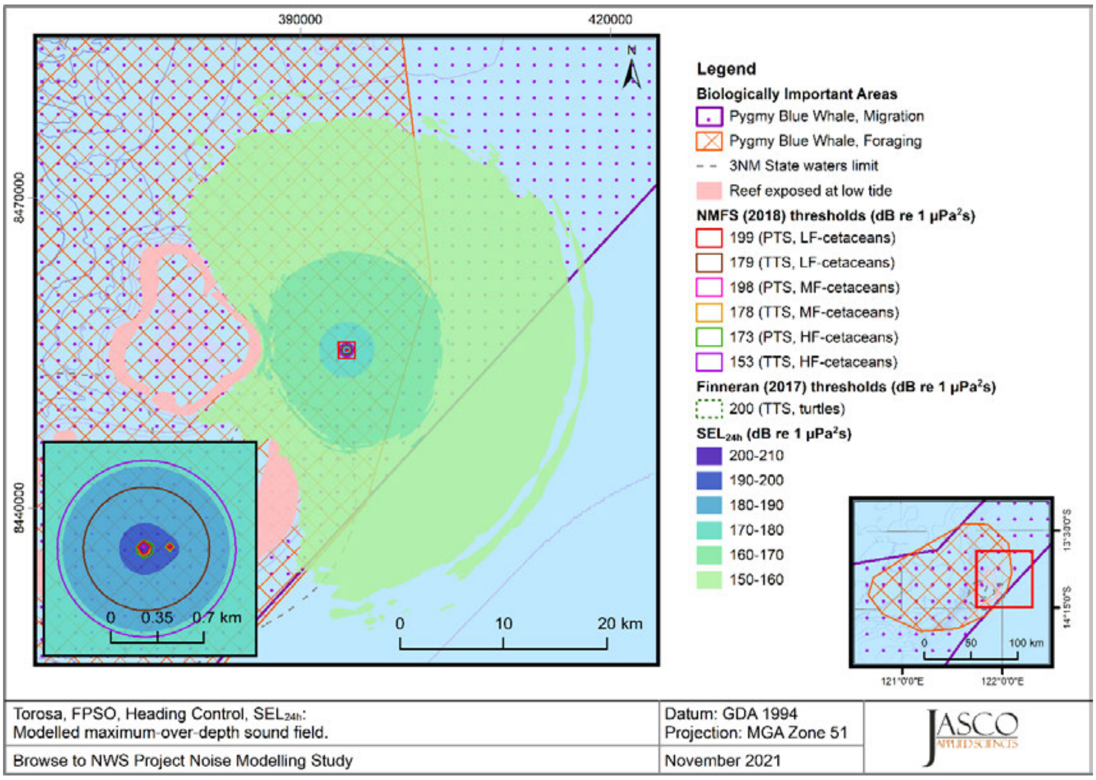

Figure 32. *Torosa location, FPSO, Heading Control. SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

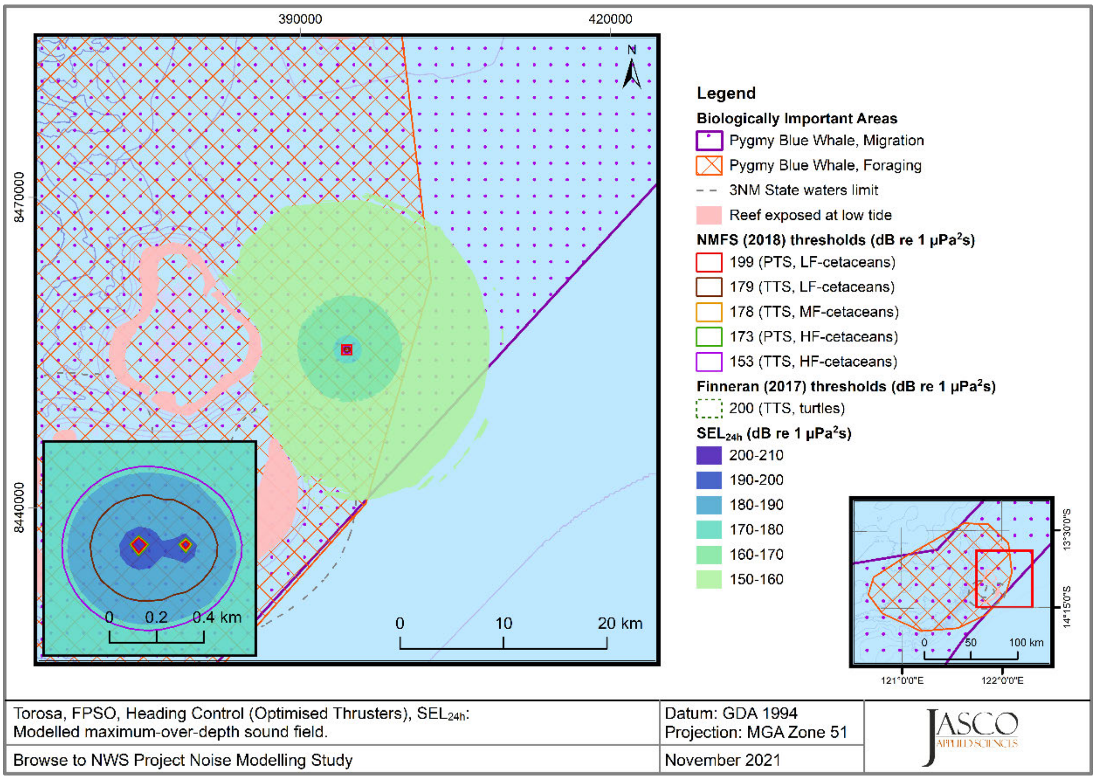

Figure 33. *Torosa FPSO, Heading Control (Optimised Thrusters), SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

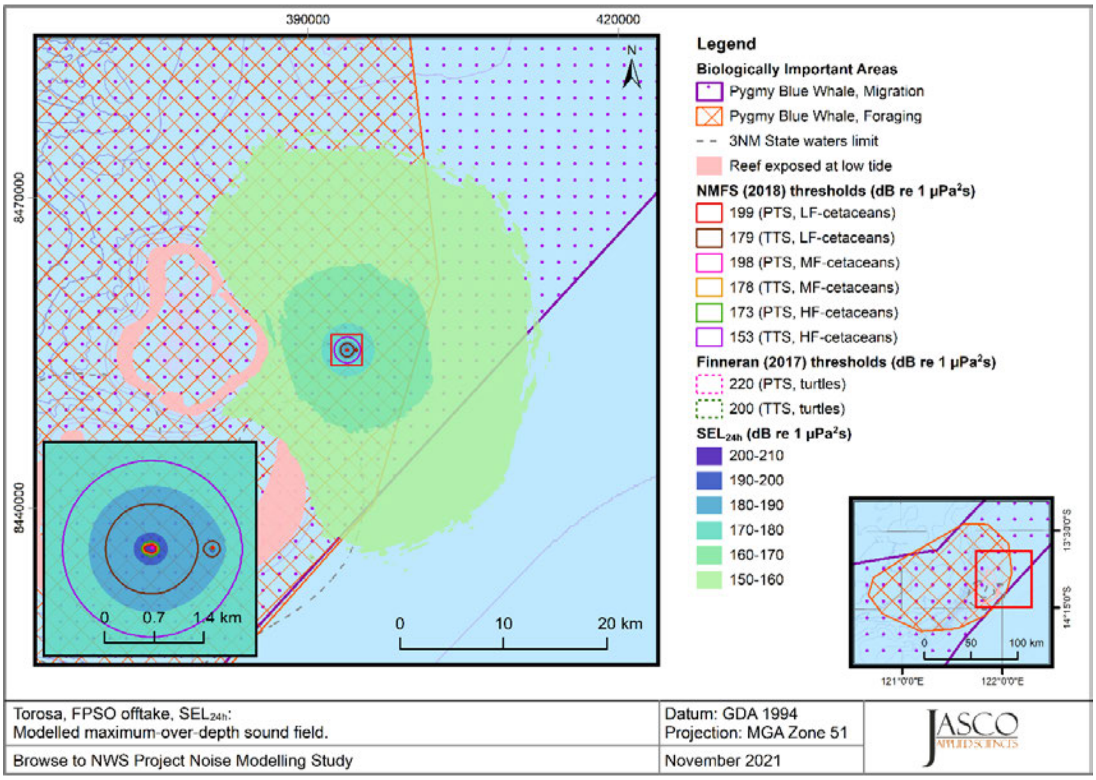

Figure 34. *Torosa location, FPSO Offtake, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

4.2.3. Aggregate Scenario

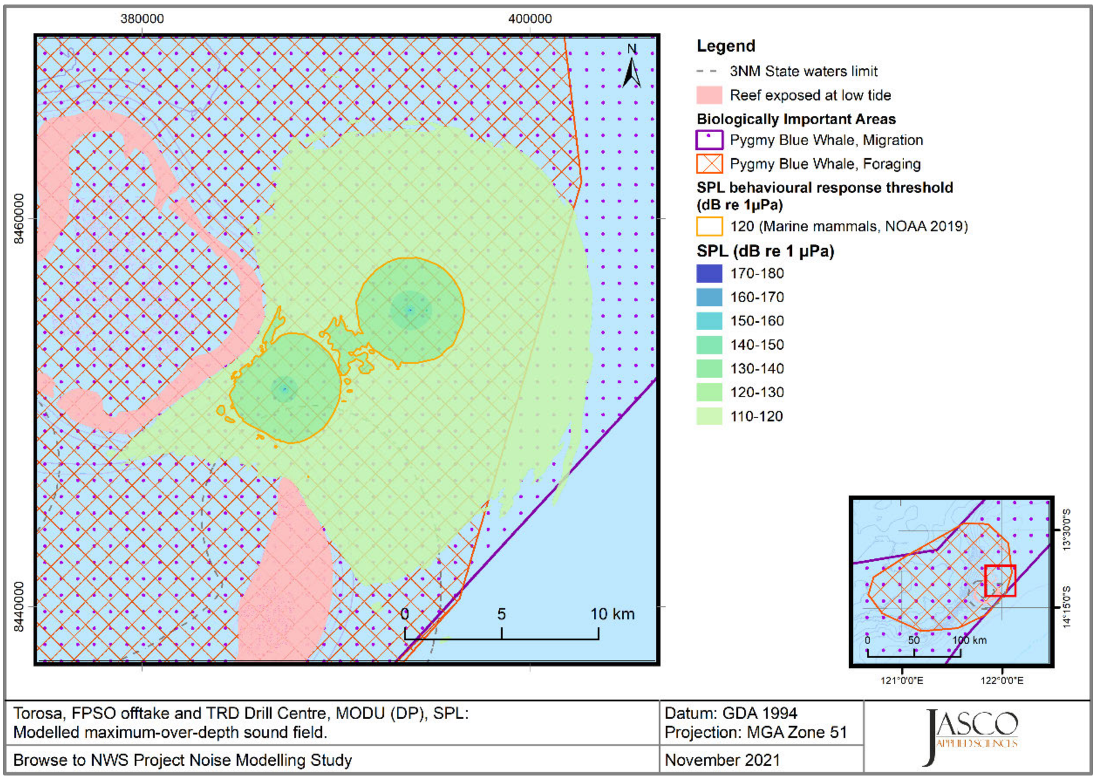

Figure 35. *Torosa FPSO location and TRD Drill centre, Aggregate FPSO offtake and MODU under DP, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

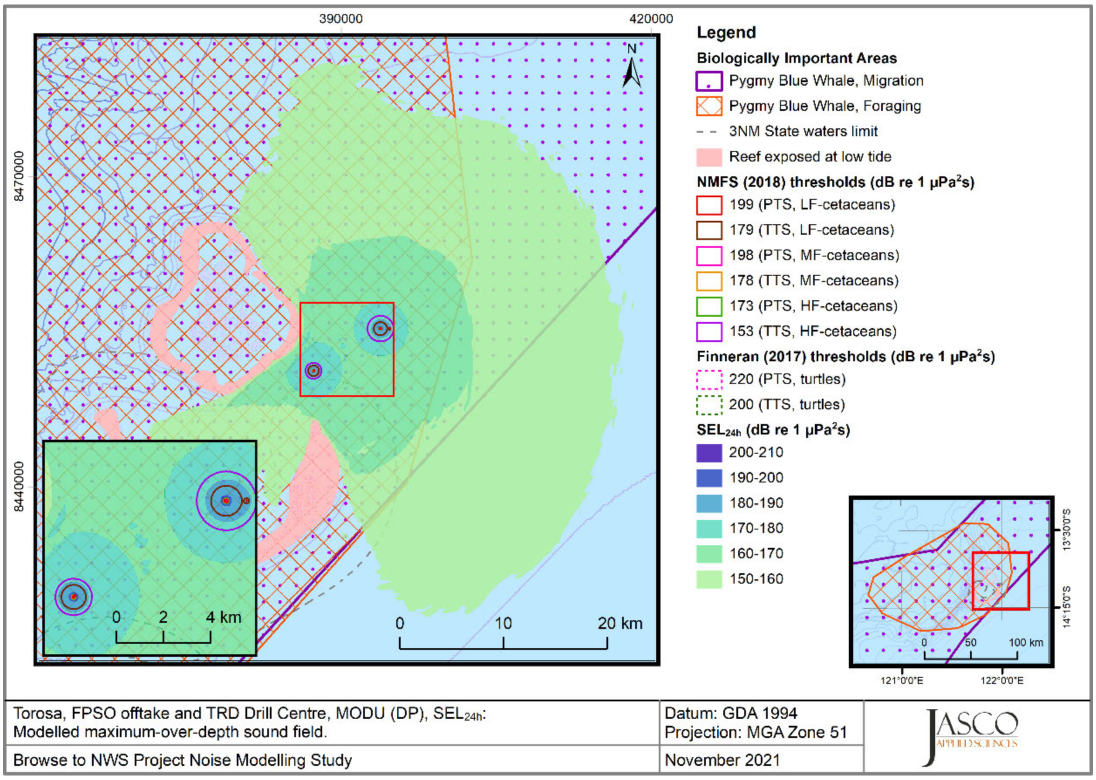

Figure 36. *TRD Drill Centre, Aggregate FPSO offtake and MODU under DP, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

5. Discussion

5.1.1. Acoustic Propagation

Results have been presented showing the propagation of sound from a dynamically positioned and moored MODU during drilling operations at both TRA and TRD drill centres, and an FPSO using heading control at Torosa, with associated offshore support vessels (OSVs). Single-vessel and combination scenarios were modelled at each location, as well as an aggregate scenario involving the MODU at the TRD drill centre and the FPSO offtake scenario at the Torosa field.

The main influence on sound propagation is the bathymetry in the local area. In particular, the nearby presence of Scott Reef blocks most propagation in westerly and south-westerly directions. This is especially true of sources at the TRA and TRD drill centres, as both of these are closer to the reef than the facility at Torosa. Looking at the maps in Figures 17–19, it can be seen that the presence of Scott Reef does not significantly affect propagation from Torosa at the levels of interest for SPL, whereas Figures 9–16 clearly show the effect of the reef on the propagation from the TRA and TRD drill centres. The SEL_{24h} levels are visibly affected by the reef from all sites, though not at ranges that affect any relevant thresholds (see Figures 20–34).

5.1.2. Exposure Thresholds

At the TRA and TRD drill centres, there are several significant effects of combining the MODU (under DP) and OSV sources in the resupply scenarios. At the TRA drill centre, the SPL behavioural threshold range for marine mammals is almost 5 km for the resupply scenario, and at the TRD drill centre it exceeds 5 km, whereas it is between 2–4.5 km for scenarios with single vessels including thruster sources. This is mirrored in SEL_{24h} TTS threshold ranges for high-frequency cetaceans, which are above 0.9 km for multi-vessel scenarios, but generally less than 0.8 km for single-vessel scenarios (see Tables 17 and 18). The omission of the thrusters in the 'moored' MODU scenarios significantly reduce threshold ranges, from 4.49 km to 0.5 km for marine mammal behavioural disturbance, and from 0.77 km to 0.3 km for the high-frequency cetacean TTS threshold.

One phenomenon of note is that the FPSO offtake scenario has a shorter range to the 120 dB marine mammal SPL disturbance threshold (2.67 km) than the standalone FPSO on heading control scenario (2.82 km; see Table 14). This is despite the fact that the broadband source level of the OSV, the dominant source in the offtake scenario, is 185.5 dB re 1 µPa, whereas the broadband source level of the FPSO with heading control is lower, at 183 dB re 1 µPa. The machinery source on the FPSO has much more energy at low frequencies than any of the thruster sources on the OSV. These low frequencies are less readily absorbed, and it is possible this is causing the observed effect. This is also reflected in the fact that at levels above 130 dB, ranges are shorter for the offtake scenario than for the FPSO on heading control scenario.

For the aggregate scenario including both FPSO offtake and the MODU under DP at the TRD drill centre, it was found that due to the separation between the sites, ranges to PTS and TTS thresholds (Table 22) were not significantly different than the individual operations (Tables 18 and 19). Maximum behavioural threshold ranges (Table 20), on the other hand, increased by 580 m relative to the MODU operating in isolation under DP (Tables 13 and 14). The $R_{95\%}$, however, is not significantly altered from either scenario in isolation, indicating that this increase in $R_{\max}$ is probably due to a specific propagation path between the two sites (see Figure 35).

Glossary

Unless otherwise stated in an entry, these definitions are consistent with ISO 80000-3 (2017).

absorption

The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium.

animal movement modelling

Simulation of animal movement based on behavioural rules for the purpose of predicting an animal's experience of an environment.

attenuation

The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

auditory frequency weighting

The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2007).

auditory frequency weighting function

Frequency weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity. Example hearing groups are low-, mid-, and high-frequency cetaceans, phocid and otariid pinnipeds.

azimuth

A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

broadband level

The total level measured over a specified frequency range.

cetacean

Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises.

continuous sound

A sound whose sound pressure level remains above ambient sound during the observation period . A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006).

decidecade

One tenth of a decade. *Note*: An alternative name for decidecade (symbol ddec) is "one-tenth decade". A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a "one-third octave".

decidecade band

Frequency band whose bandwidth is one decidecade. *Note*: The bandwidth of a decidecade band increases with increasing centre frequency.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB.

ensonified

Exposed to sound.

far field

The zone where, to an observer, sound originating from an array of sources (or a spatially distributed source) appears to radiate from a single point.

flat weighting

Term indicating that no frequency weighting function is applied. Synonymous with unweighted.

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. 1 Hz is equal to 1 cycle per second.

frequency weighting

The process of applying a frequency weighting function.

frequency-weighting function

The squared magnitude of the sound pressure transfer function. For sound of a given frequency, the frequency weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency weighting function*: compensatory frequency weighting function accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
- *System frequency weighting function*: frequency weighting function describing the sensitivity of an acoustic acquisition system, typically consisting of a hydrophone, one or more amplifiers, and an analogue to digital converter.

geoacoustic

Relating to the acoustic properties of the seabed.

hearing group

Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include very low-frequency (VLF) cetaceans, low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW) (NMFS 2018, Southall et al. 2019). See **auditory frequency weighting functions**, which are often applied to these groups. Examples for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014).

hertz (Hz)

A unit of frequency defined as one cycle per second.

high-frequency (HF) cetacean

See **hearing group**.

isopleth

A line drawn on a map through all points having the same value of some quantity.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level. For example, a value of sound exposure level with reference to 1 μPa^2 s can be written in the form *x* dB re 1 μPa^2 s.

low-frequency (LF) cetacean

See **hearing group**.

mid-frequency (MF) cetacean

See **hearing group**.

monopole source level (MSL)

A source level that has been calculated using an acoustic model that accounts for the effect of the sea-surface and seabed on sound propagation, assuming a point-like (monopole) sound source. Also see **radiated noise level**.

M-weighting

See **auditory frequency weighting function** (as proposed by Southall et al. 2007).

N percent exceedance level

The sound level exceeded *N*% of the time during a specified time interval. Also see **percentile level**.

non-impulsive sound

Sound that is not an impulsive sound. A non-impulsive sound is not necessarily a continuous sound.

octave

The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

parabolic equation method

A computationally efficient solution to the acoustic wave equation that is used to model propagation loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of propagation loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

percentile level

The sound level not exceeded *N*% of the time during a specified time interval. The *N*th percentile level is equal to the (100−*N*)% exceedance level. Also see ***N* percent exceedance level**.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

point source

A source that radiates sound as if from a single point.

pressure, acoustic

The deviation from the ambient pressure caused by a sound wave. Also called sound pressure.
Unit: pascal (Pa).

propagation loss (PL)

Difference between a source level (SL) and the level at a specified location, PL(x) = SL − L(x). Also see **transmission loss**.

radiated noise level (RNL)

A source level that has been calculated assuming sound pressure decays geometrically with distance from the source, with no influence of the sea-surface and seabed. Also see **monopole source level**.

received level

The level measured (or that would be measured) at a defined location. The type of level should be specified.

reference values

standard underwater references values used for calculating sound **levels**, e.g., the reference value for expressing sound pressure level in decibels is 1 µPa.

Quantity	Reference value
Sound pressure	1 µPa
Sound exposure	1 µPa^2 s
Sound particle displacement	1 pm
Sound particle velocity	1 nm/s
Sound particle acceleration	1 µm/s^2

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium.

sound exposure

Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 hours) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2 s.

sound exposure level

The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 µPa^2 s.

$$L_E := 10\log_{10}(E/E_0)\ \mathrm{dB} \ = 20\log_{10}\left(E^{1/2}/E_0^{1/2}\right)\ \mathrm{dB}$$

The frequency band and integration time should be specified. Abbreviation: SEL.

sound field

Region containing sound waves.

sound pressure

The contribution to total pressure caused by the action of sound.

sound pressure level (rms sound pressure level)

The level ($L_{p,\mathrm{rms}}$) of the time-mean-square sound pressure (p_{rms}^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2.

$$L_{p,\mathrm{rms}} := 10\log_{10}(p_{\mathrm{rms}}^2/p_0^2)\ \mathrm{dB}\ = 20\log_{10}(p_{\mathrm{rms}}/p_0)\ \mathrm{dB}$$

The frequency band and averaging time should be specified. Abbreviation: SPL or Lrms.

sound speed profile

The speed of sound in the water column as a function of depth below the water surface.

source level (SL)

A property of a sound source obtained by adding to the sound pressure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 μPa^{2}m^2.

spectrum

An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound exposure distribution with frequency.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity. TTS can be caused by noise exposure.

transmission loss (TL)

The difference between a specified level at one location and that at a different location,
TL(x1,x2) = L(x1) − L(x2).

unweighted

Term indicating that no frequency weighting function is applied. Synonymous with flat weighting.

Literature Cited

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Appendix A. Underwater Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially pulsed sound such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate sound and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow International Organization for Standardization definitions and symbols for sound metrics (e.g., ISO 2017, ANSI S1.1-2013).

A.1. Acoustic Metrics

The sound pressure level (SPL or L_p; dB re 1 μPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s). It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T g(t)\,p^2(t)\,dt\Big/p_0^2\right)\text{ dB} \tag{A-1}$$

where $g(t)$ is an optional time weighting function. In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal. For in-air studies, when evaluating the perceived loudness of sounds with rapid amplitude variations in time, the time weighting function $g(t)$ is often set to a decaying exponential function that emphasizes more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. For example, human-based fast time-weighted SPL ($L_{p,fast}$) applies an exponential function with time constant 125 ms. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function of width 125 ms; the results can be referred to as $L_{p,boxcar\ 125ms}$. Another approach, historically used to evaluate SPL of impulsive signals underwater, defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5% and 95% of the cumulative square pressure function encompassing the duration of an impulsive acoustic event. This calculation is applied individually to each impulse signal, and the results have been referred to as 90% SPL ($L_{p,90\%}$).

The sound exposure level (SEL or L_E; dB re 1 μPa^2 s) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_E = 10\log_{10}\left(\int_T p^2(t)\,dt\Big/T_0 p_0^2\right)\text{ dB} \tag{A-2}$$

where T_0 is a reference time interval of 1 s. SEL continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered for its relevance to impact to the exposed recipients.

SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events. When applied to pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}}\right)\ \mathrm{dB} \tag{A-3}$$

Because the SPL(T_{90}) and SEL are both computed from the integral of square pressure, these metrics are related numerically by the following expression, which depends only on the duration of the time window T:

$$L_p = L_E - 10\log_{10}(T) \tag{A-4}$$

$$L_{p90} = L_{\mathrm{E}} - 10\log_{10}(T_{90}) - 0.458 \tag{A-5}$$

where the 0.458 dB factor accounts for the 10% of pulse SEL missing from the SPL(T_{90}) integration time window.

Energy equivalent SPL (L_{eq}; dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $p(t)$, over the same time period, T:

$$L_{\mathrm{eq}} = 10\log_{10}\left(\frac{1}{T}\int_{T} p^2(t)\,dt \Big/ p_0^2\right) \tag{A-6}$$

The equations for SPL and the energy-equivalent SPL are numerically identical. Conceptually, the difference between the two metrics is that the SPL is typically computed over short periods (typically of 1 s or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the L_{eq} reflects the average SPL of an acoustic signal over time periods typically of 1 min to several hours.

A.2. Decidecade Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analysing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. A decidecade is sometimes referred to as a "1/3-octave" because one tenth of a decade is approximately equal to one third of an octave. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The centre frequency of the ith band, $f_{\mathrm{c}}(i)$, is defined as:

$$f_{\mathrm{c}}(i) = 10^{\frac{i}{10}}\ \mathrm{kHz} \tag{A-7}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith decade band are defined as:

$$f_{\mathrm{lo},i} = 10^{\frac{-1}{20}} f_{\mathrm{c}}(i) \quad \text{and} \quad f_{\mathrm{hi},i} = 10^{\frac{1}{20}} f_{\mathrm{c}}(i) \tag{A-8}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-1). The acoustic modelling spans from band $f_c(1) = 10\ Hz$ to $f_c(37) = 63\ kHz$.

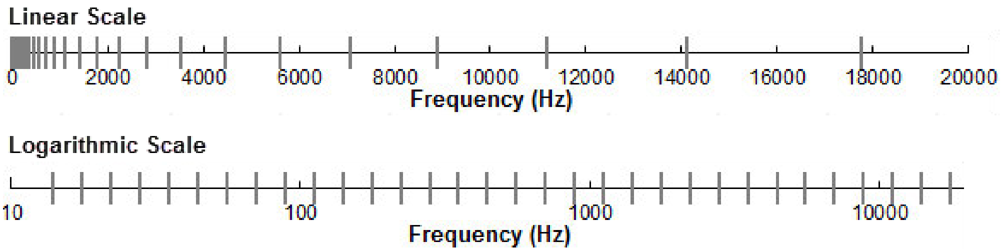

Figure A-1. Decidecade frequency bands (vertical lines) shown on both linear and logarithmic frequency scales

The sound pressure level in the ith band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{\mathrm{lo},i}$ and $f_{\mathrm{hi},i}$:

$$L_{p,i} = 10\log_{10}\int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\,\mathrm{d}f \;\; \mathrm{dB} \tag{A-9}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10\log_{10}\sum_{i} 10^{\frac{L_{p,i}}{10}}\,\mathrm{dB} \tag{A-10}$$

Figure A-2 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient sound signal. Because the decidecade bands are wider than 1 Hz, the decidecade band SPL is higher than the spectral levels at higher frequencies. Acoustic modelling of decidecade bands requires less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

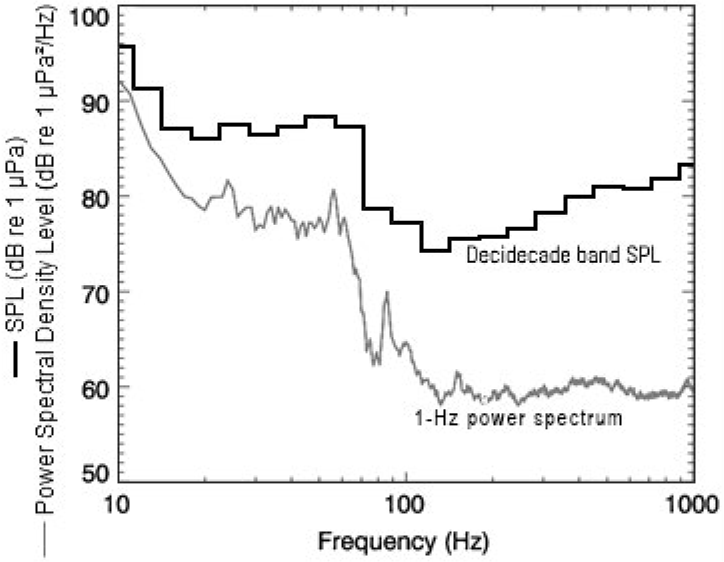

Figure A-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient sound shown on a logarithmic frequency scale. Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the power spectrum.

A.3. Marine Mammal Impact Criteria

It has been long recognised that marine mammals can be adversely affected by underwater anthropogenic noise. For example, Payne and Webb (1971) suggested that communication distances of fin whales are reduced by shipping sounds. Subsequently, similar concerns arose regarding effects of other underwater noise sources and the possibility that impulsive sources—primarily airguns used in seismic surveys—could cause auditory injury. This led to a series of workshops held in the late 1990s, conducted to address acoustic mitigation requirements for seismic surveys and other underwater noise sources (NMFS 1998, ONR 1998, Nedwell and Turnpenny 1998, HESS 1999, Ellison and Stein 1999). In the years since these early workshops, a variety of thresholds have been proposed for both injury and disturbance. The following sections summarize the recent development of thresholds; however, this field remains an active research topic.

A.3.1. Injury and Hearing Sensitivity Changes

In recognition of shortcomings of the SPL-only based injury criteria, in 2005 NMFS sponsored the Noise Criteria Group to review literature on marine mammal hearing to propose new noise exposure criteria. Some members of this expert group published a landmark paper (Southall et al. 2007) that suggested assessment methods similar to those applied for humans. The resulting recommendations introduced dual acoustic injury criteria for impulsive sounds that included peak pressure level thresholds and SEL_{24h} thresholds, where the subscripted 24h refers to the accumulation period for calculating SEL. The peak pressure level criterion is not frequency weighted whereas SEL_{24h} is frequency weighted according to one of four marine mammal species hearing groups: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively) and Pinnipeds in Water (PINN). These weighting functions are referred to as M-weighting filters (analogous to the A-weighting filter for human; Appendix A.3.3). The SEL_{24h} thresholds were obtained by extrapolating measurements of onset levels of Temporary Threshold Shift (TTS) in belugas by the amount of TTS required to produce Permanent Threshold Shift (PTS) in chinchillas. The Southall et al. (2007) recommendations do not specify an exchange rate, which suggests that the thresholds are the same regardless of the duration of exposure (i.e., it implies a 3 dB exchange rate).

Wood et al. (2012) refined Southall et al.’s (2007) thresholds, suggesting lower injury values for LF and HF cetaceans while retaining the filter shapes. Their revised thresholds were based on TTS-onset levels in harbour porpoises from Lucke et al. (2009), which led to a revised impulsive sound PTS threshold for HF cetaceans of 179 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$. Because there were no data available for baleen whales, Wood et al. (2012) based their recommendations for LF cetaceans on results obtained from MF cetacean studies. In particular they referenced Finneran and Schlundt (2010) research, which found mid-frequency cetaceans are more sensitive to non-impulsive sound exposure than Southall et al. (2007) assumed. Wood et al. (2012) thus recommended a more conservative TTS-onset level for LF cetaceans of 192 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$.

As of 2017, an optimal approach is not apparent. There is consensus in the research community that an SEL-based method is preferable either separately or in addition to an SPL-based approach to assess the potential for injuries. In August 2016, after substantial public and expert input into three draft versions and based largely on the above-mentioned literature (NOAA 2013, 2015, 2016), NMFS finalised technical guidance for assessing the effect of anthropogenic sound on marine mammal hearing (NMFS 2016). The guidance describes injury criteria with new thresholds and frequency weighting functions for the five hearing groups described by Finneran and Jenkins (2012). The latest revision to this work was published in 2018 (NMFS 2018). Southall et al. (2019) revisited the interim criteria published in 2007; all noise exposure criteria in NMFS (2018) and Southall et al. (2019) are identical (for impulsive and non-impulsive sounds), however the mid-frequency cetaceans from NMFS (2018) are classified as high-frequency cetaceans in Southall et al. (2019), and high-frequency cetaceans from NMFS (2018) are classified as very-high-frequency cetaceans in Southall et al. (2019).

A.3.2. Behavioural response

Numerous studies on marine mammal behavioural responses to sound exposure have not resulted in consensus in the scientific community regarding the appropriate metric for assessing behavioural reactions. However, it is recognised that the context in which the sound is received affects the nature and extent of responses to a stimulus (Southall et al. 2007, Ellison and Frankel 2012, Southall et al. 2016).

NMFS currently uses step function (all-or-none) threshold of 120 dB re 1 µPa SPL (unweighted) for non-impulsive sounds to assess and regulate noise-induced behavioural effects to marine mammals (NOAA 2019). The 120 dB re 1 µPa threshold is associated with continuous sources and was derived based on studies examining behavioural responses to drilling and dredging, referring to Malme et al. (1983), Malme et al. (1984), and Malme et al. (1986), which were considered in Southall et al. (2007). Malme et al. (1986) found that playback of drillship noise did not produce clear evidence of disturbance or avoidance for levels below 110 dB re 1 µPa (SPL), possible avoidance occurred for exposure levels approaching 119 dB re 1 µPa. Malme et al. (1984) determined that measurable reactions usually consisted of rather subtle short-term changes in speed and/or heading of the whale(s) under observation. It has been shown that both received level and proximity of the sound source is a contributing factor in eliciting behavioural reactions in humpback whales (Dunlop et al. 2017, Dunlop et al. 2018).

A.3.3. Marine Mammal Frequency Weighting

The potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is expressed as:

$$G(f) = K + 10\log_{10}\left(\frac{\left(\frac{f}{f_{lo}}\right)^{2a}}{\left(1+\left(\frac{f}{f_{lo}}\right)^{2}\right)^{a}\left(1+\left(\frac{f}{f_{hi}}\right)^{2}\right)^{b}}\right) \tag{A-11}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans, phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses noise impacts on marine mammals (NMFS 2016, NMFS 2018). A further update to these weighting functions is presented in Southall (2019), whereby mid- and high- frequency cetaceans are now known as high- and very-high-frequency cetaceans. Table A-1 lists the frequency-weighting parameters for each hearing group; Figure A-3 shows the resulting frequency-weighting curves.

Table A-1. Parameters for the auditory weighting functions used in this project as recommended by NMFS (2018) and Finneran et al. (2017).

Hearing group	a	b	f_{lo} (Hz)	f_{hi} (Hz)	K (dB)
LF cetaceans (baleen whales)	1.0	2	200	19,000	0.13
MF cetaceans (dolphins, plus toothed, beaked, and bottlenose whales)	1.6	2	8,800	110,000	1.20
HF cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	1.8	2	12,000	140,000	1.36
Sea turtles	1.4	2	77	440	2.35

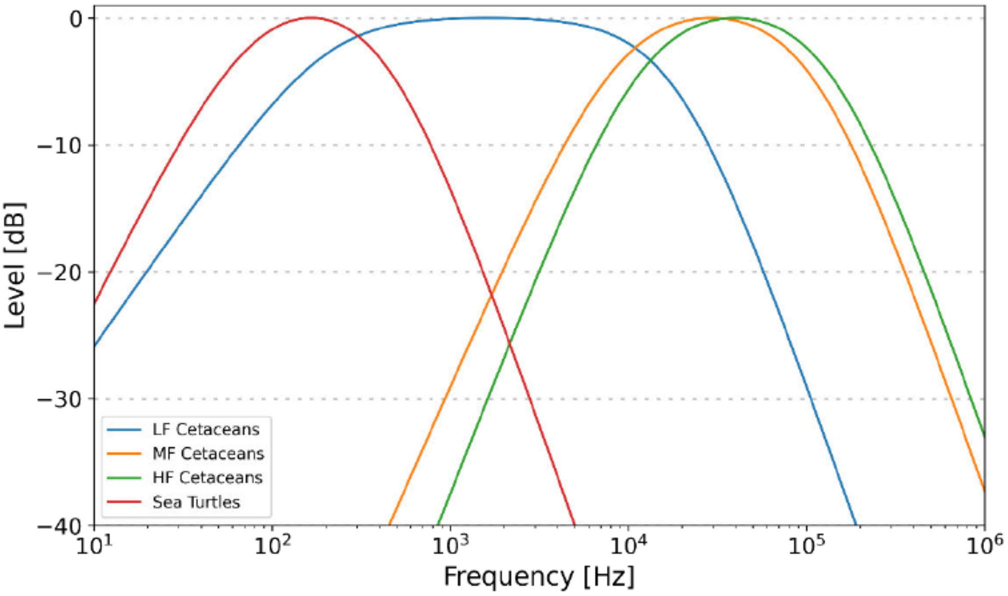

Figure A-3. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018) and Finneran et al. (2017)

Appendix B. Sound Source Propagation

B.1. Marine Operations Noise Model

Underwater sound propagation (i.e., transmission loss) at frequencies of 10 Hz to 1.6 kHz was predicted with JASCO's Marine Operations Noise Model (MONM). MONM computes SEL over 1 s for non-impulsive sources, at a specified source depth. Sound propagation at frequencies of 2 kHz and greater was computed via the BELLHOP Gaussian beam acoustic ray-trace model (Porter and Liu 1994).

MONM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the US Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for a solid seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM accounts for the additional reflection loss at the seabed, which results from partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates the following site-specific environmental properties: a bathymetric grid of the modelled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor. Additionally, BELLHOP accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water (Fisher and Simmons 1977). This type of sound attenuation is important for frequencies higher than 5 kHz and cannot be neglected without noticeably affecting the model results.

MONM computes acoustic fields in three dimensions by modelling transmission loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as *N*×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding $N = 360°/\Delta\theta$ number of planes (Figure B-1).

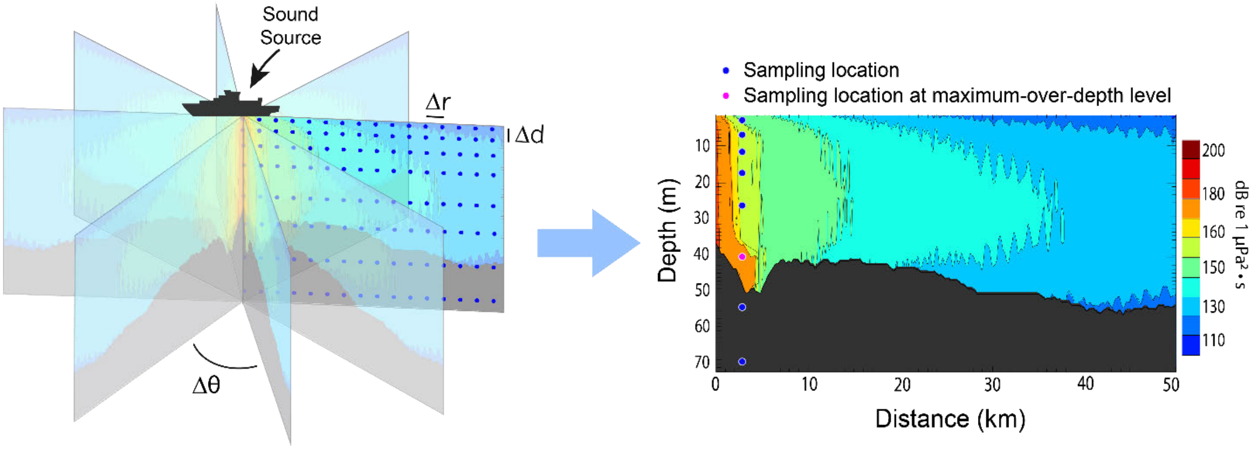

Figure B-1. The *N*×2-D and maximum-over-depth modelling approach used by MONM

MONM treats frequency dependence by computing acoustic transmission loss at the centre frequencies of decidecade bands. Sufficiently many decidecade frequency-bands, starting at 10 Hz, are modelled to include most of the acoustic energy emitted by the source. At each centre frequency, the transmission loss is modelled within each of the N vertical planes as a function of depth and range from the source. The decidecade received per-pulse SEL are computed by subtracting the band propagation loss values from the directional source level in that frequency band. Composite broadband received per-pulse SEL are then computed by summing the received decidecade levels.

The received per-pulse SEL sound field within each vertical radial plane is sampled at various ranges from the source, generally with a fixed radial step size (Δr in Figure B-1). At each sampling range along the surface, the sound field is sampled at various depths (Δd in Figure B-1), with the step size between samples increasing with depth below the surface. The step sizes are chosen to provide increased coverage near the depth of the source and at depths of interest for the sound speed profile. For areas with deep water, sampling is not performed at depths beyond those reachable by marine mammals. The received per-pulse SEL at a surface sampling location is taken as the maximum value that occurs over all samples within the water column, i.e., the maximum-over-depth received per-pulse SEL. These maximum-over-depth per-pulse SEL are presented as colour contours around the source.

MONM's predictions have been validated against experimental data from several underwater acoustic measurement programs conducted by JASCO (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010, Racca et al. 2012a, Racca et al. 2012b, Martin et al. 2015).

Appendix C. Additional Methods and Parameters

C.1. Estimating Ranges to Threshold Levels

Sound level contours were calculated based on the underwater sound fields predicted by the propagation models, sampled by taking the maximum value over all modelled depths above the seafloor for each location in the modelled region. The predicted ranges to specific levels were computed from these contours. Two ranges relative to the source are reported for each sound level: R_{max}, the maximum range to the given sound level over all azimuths, and $R_{95\%}$, the range to the given sound level after the 5% farthest points were excluded (see examples in Figure C.1).

The $R_{95\%}$ is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in Figure C.1a. In cases such as this, where relatively few points are excluded in any given direction, R_{max} can misrepresent the area of the region exposed to such effects, and $R_{95\%}$ is considered more representative. In contrast, in strongly radially asymmetric cases such as shown in Figure C.1b, $R_{95\%}$ neglects to account for substantial protrusions in the footprint. In such cases, R_{max} might better represent the region of effect in specific directions. Cases such as this are usually associated with bathymetric features that affect propagation. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the non-uniformity of the acoustic environment.

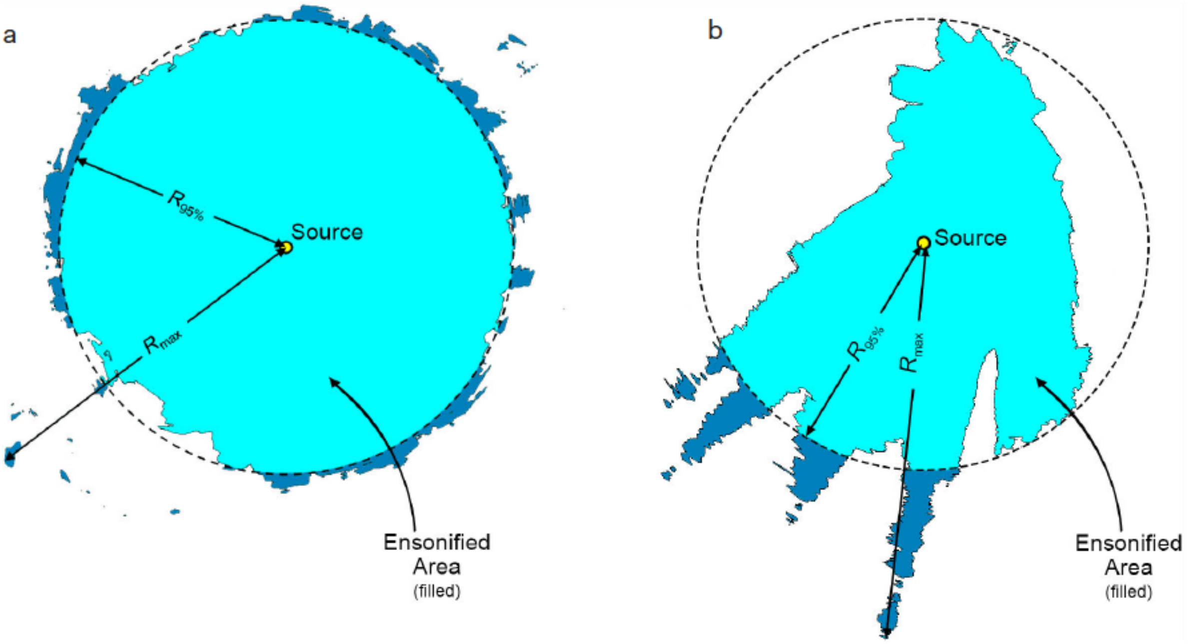

Figure C.1. R_{max} and $R_{95\%}$ ranges shown for two contrasting scenarios. Cyan indicates the ensonified areas bounded by $R_{95\%}$, whilst dark blue indicates the ensonified areas beyond $R_{95\%}$ that determine R_{max}.

C.2. Environmental Parameters

The parameters used are the same as applied in McPherson et al. (2019).

C.2.1. Bathymetry

Water depths (Mean Sea Level) at close- and mid-range from the pile were provided by Woodside. Within ~5–7 km from the pile, the data has a grid resolution of 2 × 2 m, while data at the passage between Scott Reef South and Scott Reef Central has a grid resolution of 1 × 1 m. Bathymetry data with grid resolution of 10 × 10 m was provided as far as 33 km northeast of the pile, and as far as 85 km southwest of the pile. Modelling was conducted along 80 km long radials emanating from the pile in all directions. For this reason, the high-resolution data was complemented using the Australian Bathymetry and Topography Grid, a 9 arc-second grid rendered for Australian waters (Whiteway 2009). The data were adjusted for an increase of 1.7 m in depth (Bureau of Meterology 2019), so the modelling results correspond to the most conservative propagation conditions at maximum tide at Scott Reef. Bathymetry data were re-gridded onto a Map Grid of Australia (MGA) coordinate projection (Zone 51) with a regular grid spacing of 50 × 50 m.

C.2.2. Sound speed profile

The sound speed profile in the area was derived from temperature and salinity profiles from the U.S. Naval Oceanographic Office’s *Generalized Digital Environmental Model V 3.0* (GDEM; Teague et al. 1990, Carnes 2009). GDEM provides an ocean climatology of temperature and salinity for the world’s oceans on a latitude-longitude grid with 0.25° resolution, with a temporal resolution of one month, based on global historical observations from the U.S. Navy’s Master Oceanographic Observational Data Set (MOODS). The climatology profiles include 78 fixed depth points to a maximum depth of 6800 m (where the ocean is that deep). The GDEM temperature-salinity profiles were converted to sound speed profiles according to Coppens (1981).

Mean monthly sound speed profiles were derived from the GDEM profiles at distances less than 76 km around the modelled site. The June sound speed profile is expected to be most favourable to longer-range sound propagation across the entire year. As such, June was selected for sound propagation modelling to ensure precautionary estimates of ranges to received sound level thresholds. Figure C-2 shows the resulting profile, which was used as input to the sound propagation modelling.

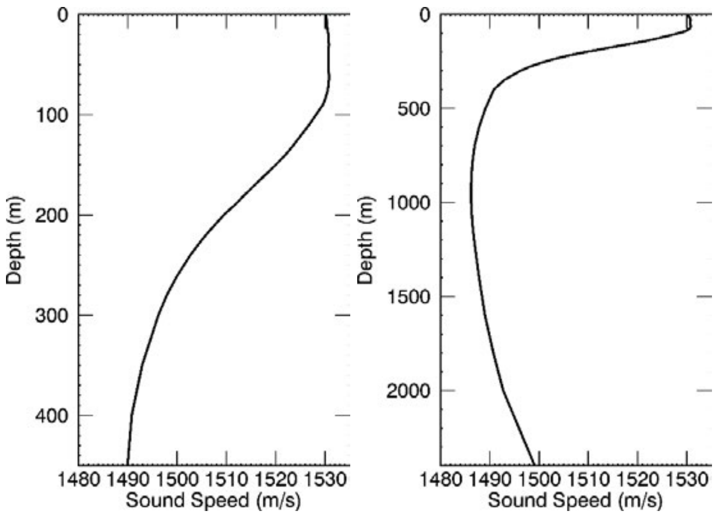

Figure C-2. The modelling sound speed profile corresponding to June: (left) top 450 m and (right) full profile. Profiles are calculated from temperature and salinity profiles from *Generalized Digital Environmental Model* V 3.0 (GDEM; Teague et al. 1990, Carnes 2009).

C.2.3. Geoacoustics

In previous acoustic studies in the area (Duncan 2014, McPherson et al. 2019), the modelling area was divided into three seabed types, with a silt seabed typical of the continental slope considered for most of the modelling area, and coarser gravel and limestone in the areas in and around the reefs. Due to the type of propagation modelling used in this study, however, the silt seabed was used for the entire modelling area. This is detailed in Table C-1.

Table C-1. Continental slope geoacoustic profile. Within each depth range, each parameter varies linearly within the stated range. The compressional wave is the primary wave, and the shear wave is the secondary wave.

Depth below seafloor (m)	Material	Density (g/cm^3)	Compressional wave		Shear wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0–50	Silt	1.70–1.75	1566–1627	1.0	210	1.5
50–100		1.75–1.80	1627–1686			
100–150		1.80–1.85	1686–1742			
150–200		1.85–1.90	1742–1795			
>200		1.90	1795			

Appendix B - Woodside Browse to NWS Vessel Noise Acoustic Modelling Phase 2 (Green *et al* 2022b)

Woodside Browse to NWS Vessel Noise

Acoustic Modelling Phase 2

JASCO Applied Sciences (Australia) Pty Ltd

24 May 2022

Submitted to:

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Woodside Energy
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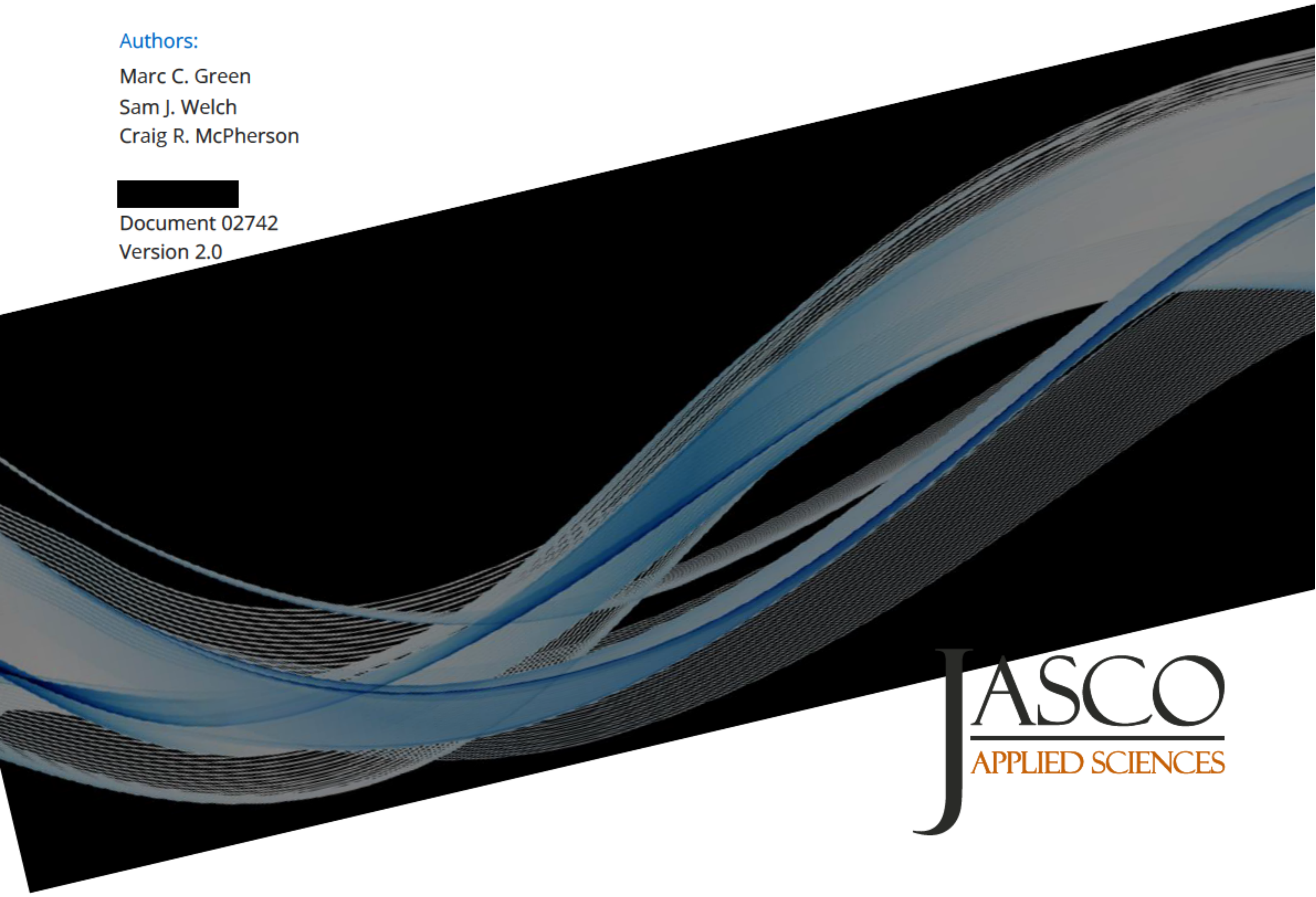

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Contents

Figures

Tables

Executive Summary

The Browse Joint Venture (BJV) proposes to develop the Brecknock, Calliance, and Torosa fields (collectively known as the Browse resources) via the development drilling of wells and the installation of a subsea production system that will supply two 1100 million standard cubic feet per day (annual daily export average) Floating Production Storage and Offloading (FPSO) facilities. The Browse Project gas will be transported from the FPSO facilities to the existing NWS Project infrastructure via an approximately 900 km long trunkline. Each FPSO will have a turret mooring system that will be stabilised using mooring lines secured to the seabed by piles. JASCO has previously modelled pile driving operations, vertical seismic profiling (VSP) during drilling operations, Mobile Offshore Drilling Unit (MODU), FPSO, and Operational Support Vessel (OSV) operations. This previous work was presented in McPherson et al. (2019) and Green et al. (2022).

The present study serves as an update to the latter, and considers the following additional scenarios based on new information from the BJV:

- Flowline installation using a flexible reel-lay vessel near the TRA drill centre.
- Initial mooring and subsea hook-up of the FPSO facility.
- Rigid pipelaying operations at three discrete locations along a line terminating at the Torosa Gas Export Riser Base (GERB).
- Resupply operations at the FPSO with various levels of thruster utilisation.

The objective of this modelling study was to determine ranges to acoustic exposure thresholds representing the best available science for permanent threshold shift (PTS), temporary threshold shift (TTS), and behavioural disturbance of marine fauna including marine mammals, turtles, and fish.

Acoustic fields caused by pressure were modelled and are presented as sound pressure levels (SPL) and accumulated sound exposure levels (SEL) as appropriate for noise effect criteria for non-impulsive (vessel) noise sources. The effects of range-dependent environmental properties on sound propagation in the study area were accounted for by the numerical models.

The modelled sources are as follows:

- The flexible reel-lay vessel Skandi *Hercules*, 109.5 m x 24 m.
- Five anchor-handling tugs, 75.3 m x 18 m, used in the initial positioning of the FPSO facility.
- The rigid pipelay vessel Saipem *Castorone*, 325 m x 39 m. This is modelled using sources representing:
  - Two forward tunnel thrusters
  - One aft tunnel thruster
  - Three forward azimuth thrusters
  - Three aft azimuth thrusters
- A B-type vessel, 141 m x 25 m, under holding DP, modelled using sources representing:
  - Two forward tunnel thrusters
  - Two aft tunnel thrusters
  - One forward azimuth thruster
  - One aft azimuth thruster

- An FPSO facility, 370 m x 67 m. This was modelled under:
    - Typical operations with no heading control, only operating processing equipment and related machinery
    - Heading control (thrusters operating), representative of typical operational conditions
    - Heading control (thrusters operating) with optimised thrusters, representative of typical operational conditions
- A representative OSV, a DP vessel 92.95 m long (vessel design based on the Marin Teknikk MT6016 hull) under DP, representative of typical operational noise during maximum safe resupply operations. This was modelled using five thruster sources operating a defined capacity, based on the specification of the *Fugro Etive*, as follows:
    - Two Rolls-Royce AZP100 thrusters, operating at 20%
    - Two Rolls Royce TT 2200 DPN thrusters, operating at 40%
    - One Rolls-Royce AZP1001 thruster, operating at 40%

The analysis considered multiple commonly used effect criteria, with the key results of the acoustic modelling summarised below.

Marine Mammals

- The results for the United States (US) National Marine Fisheries Service (NMFS 2018) criteria applied for marine mammal PTS and TTS for vessels are assessed here for a 24-hour period. Vessels are considered to be active continuously across the 24-hour period. The maximum ranges to PTS are summarised in Tables 1–3.
- The maximum ranges to the US National Oceanic and Atmospheric Administration (NOAA 2019) marine mammal behavioural response criterion of 120 dB re 1 µPa (SPL) are summarised in Table 4.

Table 1. *Marine mammal SEL_{24h} flexible reel-lay and FPSO mooring,*: Maximum (R_{max}) horizontal ranges (km) to modelled maximum-over-depth PTS thresholds from NMFS (2018).

Hearing group	Threshold for PTS, SEL_{24h} (dB re 1 µPa²s)[a]	Range R_{max} (km)	
		Flexible Reel-Lay	FPSO Mooring
LF cetaceans	199	<0.05	<0.05
MF cetaceans	198	—	—
HF cetaceans	173	<0.05	<0.05

[a] Frequency weighted.

Table 2. *Marine mammal SEL_{24h} rigid pipelay,*: Maximum (R_{max}) horizontal ranges (km) to modelled maximum-over-depth PTS thresholds from NMFS (2018).

Hearing group	Threshold for PTS, SEL_{24h} (dB re 1 µPa²s)[a]	Range R_{max} (km)		
		Final Linepipe Resupply	Mid-Point	Gas Export Riser Base
LF cetaceans	199	0.10	0.08	0.07
MF cetaceans	198	<0.05	<0.05	<0.05
HF cetaceans	173	0.20	0.15	0.15

[a] Frequency weighted.

Table 3. *Marine mammal SEL_{24h} FPSO resupply,*: Maximum (R_{max}) horizontal ranges (km) to modelled maximum-over-depth PTS thresholds from NMFS (2018).

Hearing group	Threshold for PTS, SEL_{24h} (dB re 1 µPa²s)[a]	Range R_{max} (km)		
		FPSO (Machinery Only), OSV	FPSO (Heading Control), OSV	FPSO (Optimised Heading Control), OSV
LF cetaceans	199	0.06	0.20	0.19
MF cetaceans	198	—	0.19	—
HF cetaceans	173	0.06	0.25	0.20

[a] Frequency weighted.

Table 4. *Marine mammal behaviour, all scenarios*: Summary of maximum behavioural disturbance ranges.

SPL (L_p; dB re 1 µPa)	Range R_{max} (km)							
	Flexible Reel-Lay	FPSO Mooring	Rigid Pipelay			FPSO Resupply		
			Final Line pipe Resupply	Mid-Point	Gas Export Riser Base	FPSO (Machinery Only), OSV	FPSO (Heading Control), OSV	FPSO (Optimised Heading Control), OSV
120[a]	2.16	2.44	9.85	8.30	9.40	2.29	3.92	2.54

[a] Threshold for marine mammal behavioural response to non-impulsive noise (NOAA 2019).

Sea Turtles

The maximum ranges for the Finneran et al. (2017) criteria applied for sea turtles are summarised in Table 5.

Table 5. *Sea turtle SEL_{24h}, all scenarios*: Maximum-over-depth ranges (in km) to PTS threshold.

Threshold for PTS, SEL_{24h} (dB re 1 µPa²s)[a]	Range R_{max} (km)							
	Flexible Reel-Lay	FPSO Mooring	Rigid Pipelay			FPSO Resupply		
			Final Linepipe Resupply	Mid-Point	Gas Export Riser Base	FPSO (Machinery Only), OSV	FPSO (Heading Control), OSV	FPSO (Optimised Heading Control), OSV
220[b]	—	<0.05	<0.05	<0.05	<0.05	—	—	—

[a] Frequency weighted.

[b] Threshold for turtle-weighted SEL_{24h} (Finneran et al. 2017).

A dash indicates the level was not reached.

Fish

Sound produced by the operations could cause physiological effects and recoverable injury to some fish species, but only if the animals are in proximity to the sound sources (within a planar range of 200 m) for 48 hours. Temporary impairment due to TTS could occur at similar short ranges if fish remain at the same range for long periods of time (12 hours). The ranges are very similar for all scenarios.

1. Introduction

JASCO Applied Sciences Australia (JASCO) performed a modelling study of underwater sound levels associated with the Browse to North West shelf (NWS) Project development of the Brecknock, Calliance, and Torosa fields (collectively known as the Browse resources) by the Browse Joint Venture (BJV). This development will involve drilling wells and installing a subsea production system that will supply two 1100 million standard cubic feet per day (annual daily export average) Floating Production Storage and Offloading (FPSO) facilities. Gas will be transported from the FPSO facilities to the existing NWS Project infrastructure via an approximately 900 km long trunkline. Each FPSO will have a turret mooring system that will be stabilised using mooring lines secured to the seabed by piles. JASCO has previously modelled pile driving operations, vertical seismic profiling (VSP) during drilling operations, Mobile Offshore Drilling Unit (MODU), FPSO, and Operational Support Vessel (OSV) operations. This previous work was presented in McPherson et al. (2019) and Green et al. (2022).

The present study serves as an update to the latter, and considers the following additional scenarios based on new information from the BJV:

- Flowline installation using a flexible reel-lay vessel near the TRA drill centre.
- Initial mooring and subsea hook-up of the FPSO facility.
- Rigid pipelaying operations at three discrete locations along a line terminating at the Torosa Gas Export Riser Base (GERB).
- Resupply operations at the FPSO with various levels of thruster utilisation.

The modelling study specifically assessed ranges from operations where underwater sound levels reached thresholds corresponding to various levels of impact on marine fauna. The animals considered here included marine mammals (pygmy blue whales, *Balaenoptera musculus brevicauda*), sea turtles, and fish (including fish eggs and larvae). Due to the variety of species considered, there are several thresholds for evaluating effects, including: mortality, injury, temporary reduction in hearing sensitivity, and behavioural disturbance.

The modelling methodology considered source directivity and range-dependent environmental properties. Estimated underwater acoustic levels are presented as sound pressure levels (SPL, L_p), and or accumulated sound exposure levels (SEL, L_E) as appropriate for different noise effect criteria for non-impulsive (continuous) noise sources.

1.1. Acoustic Modelling Scenario Details

The modelled sources are as follows:

- The flexible reel-lay vessel Skandi *Hercules*, 109.5 m length and 24 m breadth.
- Five anchor-handling tugs (AHTs), 75.3 m x 18 m, used in the initial positioning of the FPSO facility.
- The rigid pipelay vessel Saipem *Castorone*, 325 m x 39 m. This is modelled using sources representing:
    - Two forward tunnel thrusters
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    - One aft azimuth thruster
- An FPSO facility, 370 m x 67 m. This was modelled under:
    - Typical operations with no heading control, only operating processing equipment and related machinery
    - Heading control (thrusters operating), representative of typical operational conditions
    - Heading control (thrusters operating) with optimised thrusters, representative of typical operational conditions
- A representative OSV, a DP vessel 92.95 m long (vessel design based on the Marin Teknikk MT6016 hull) under DP, representative of typical operational noise during maximum safe resupply operations. This was modelled using five thruster sources operating a defined capacity, based on the specification of the *Fugro Etive*, as follows:
    - Two Rolls-Royce AZP100 thrusters, operating at 20%
    - Two Rolls Royce TT 2200 DPN thrusters, operating at 40%
    - One Rolls-Royce AZP1001 thruster, operating at 40%

The geographic coordinates for the modelled sites are provided in Table 6 and an overview of the modelling area is shown in Figure 1. Scenarios are summarised in Table 7.

For the FPSO mooring scenario, one AHT is positioned directly alongside the final position of the FPSO, with the remaining four positioned 500 m distant from the FPSO in the four ordinal directions, as shown in Figure 2.

For the rigid pipelay scenario, no resupply will be required for the final 10 km of the pipelay. Hence, the rigid pipelay vessel has been modelled with the attendant B-type vessel at this final resupply location, and with no B-type for subsequent modelling locations approaching the GERB (Table 7).

Figure 3 shows the relative positioning of the two vessels for the FPSO resupply scenario. This scenario is somewhat similar to the offtake scenario presented in the previous study (Green et al. 2022). In the resupply scenario in the current study, however, the OSV is positioned directly alongside the FPSO (Figure 3), whereas in the offtake scenario from Green et al. 2022 it was located 700 m away.

Table 6. Location details for the modelled sites

Site	Source	Latitude (S)	Longitude (E)	MGA (GDA94), Zone 51		Water depth (m)
				X (m)	Y (m)	
TRA Well	Skandi Hercules	13° 58′ 12.50″	121° 58′ 37.70″	389521	8455338	425
Torosa	FPSO (centre)	13° 58′ 15.06″	122° 01′ 28.53″	394647	8455281	463
	OSV (centre)	13° 58′ 15.06″	122° 01′ 28.53″	394647	8455324	463
Rigid Pipelay Line	Final Resupply	14° 04′ 06.20″	122° 01′ 58.48″	395590	8444496	478
	Mid-Point	14° 01′ 24.25″	122° 01′ 42.66″	395095	8449470	467
	GERB	13° 58′ 41.81″	122° 01′ 26.78″	394598	8454459	462

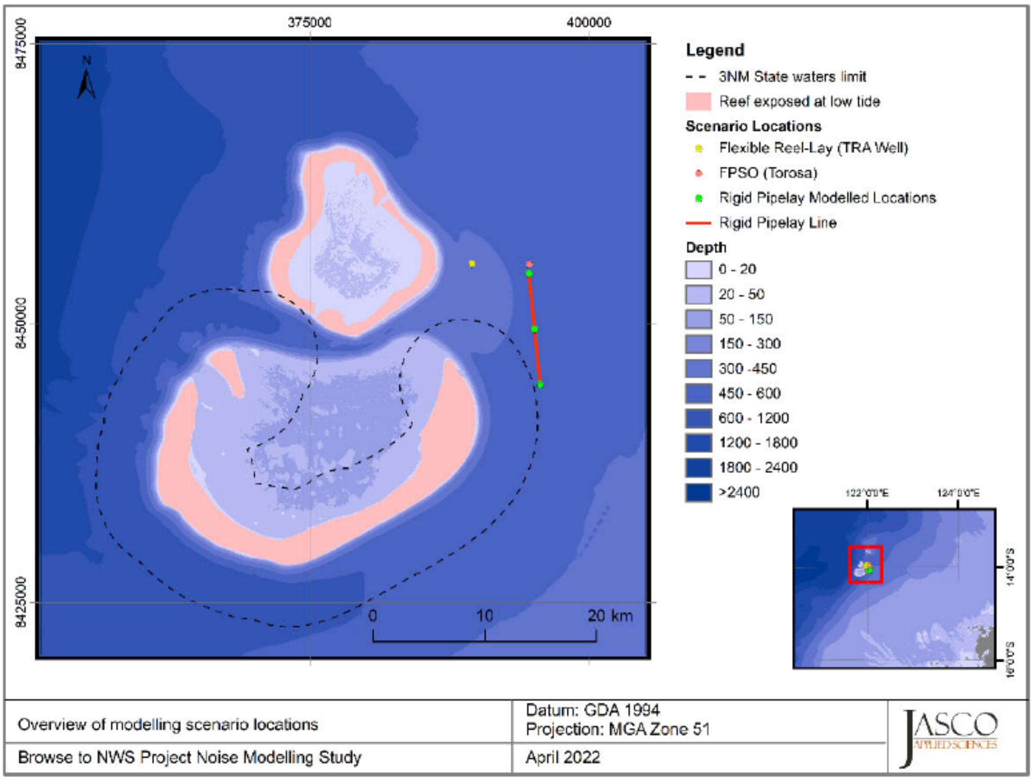

Figure 1. Overview of the modelled area and local features

Table 7. Modelled scenarios

Scenario	Description	Sources
1	Flexible Reel-Lay	Skandi Hercules, Single Monopole Source
2	FPSO Mooring and Subsea Hookup	5 x Anchor Handling Tugs
3(a)	Rigid Pipelay at Final Resupply Location	Castorone Thrusters (3 x tunnel, 6 x azimuth) B-type Thrusters (4 x tunnel, 2 x azimuth)
3(b)	Rigid Pipelay at Mid-Point	Castorone Thrusters (3 x tunnel, 6 x azimuth)
3(c)	Rigid Pipelay at GERB	
4(a)	FPSO Resupply (Machinery Only)	FPSO Machinery OSV Thrusters x 5
4(b)	FPSO Resupply (50% Thrusters)	FPSO Machinery FPSO Thrusters x 2 OSV Thrusters x 5
4(c)	FPSO Resupply (Mitigated Thrusters)	FPSO Machinery FPSO Thrusters x 2 (Reduced Level) OSV Thrusters x 5

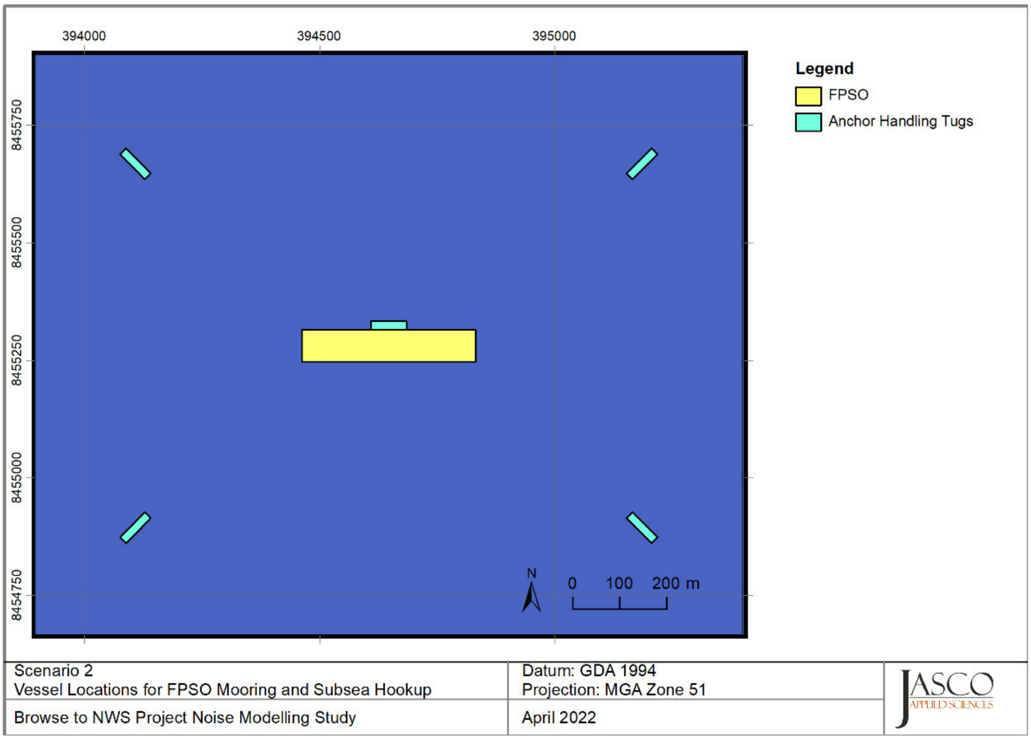

Figure 2. Overview of anchor handling tug source positioning for Scenario 2 relative to final positioning of FPSO. Note that in this scenario, the FPSO is treated as silent since it is neither utilising thrusters nor processing hydrocarbons.

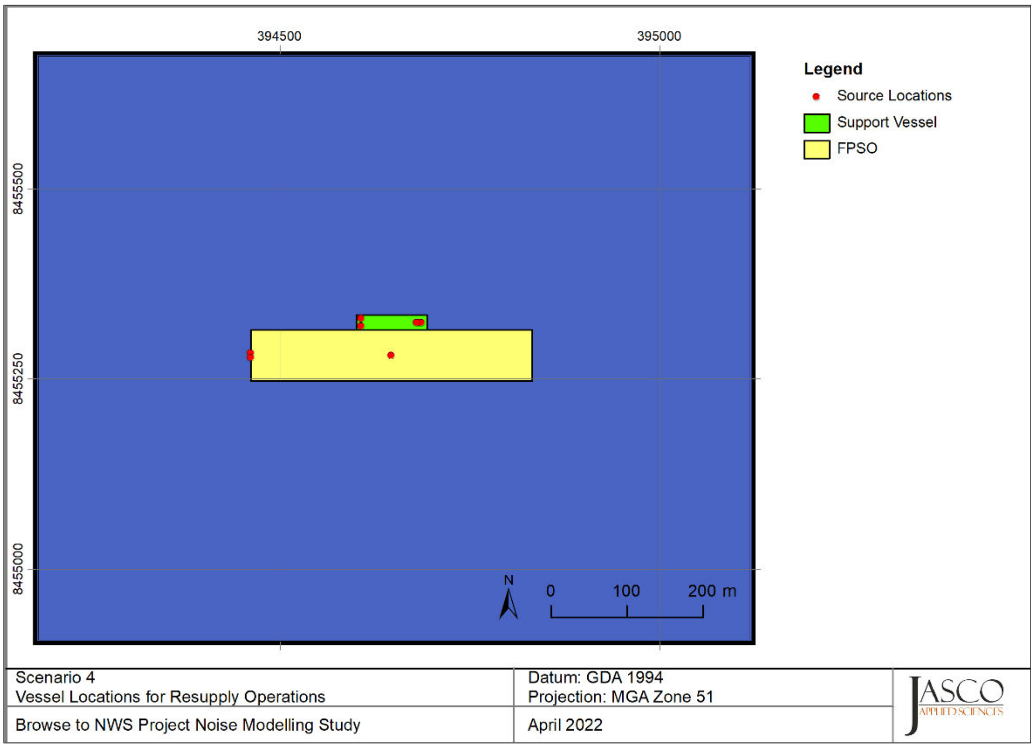

Figure 3. Overview of FPSO and OSV positioning for Scenario 4.

2. Noise Effect Criteria

To assess the potential impacts of a sound-producing activity, it is necessary to first establish exposure criteria (thresholds) for which sound levels may be expected to have a negative impact on animals. Whether acoustic exposure levels might injure or disturb marine fauna is an active research topic. Since 2007, several expert groups have developed SEL-based assessment approaches for evaluating auditory injury, with key works including Southall et al. (2007), Finneran and Jenkins (2012), Popper et al. (2014), and the United States National Marine Fisheries Service (NMFS 2018). The number of studies that investigate the level of behavioural disturbance to marine fauna by anthropogenic sound has also increased substantially.

Several sound level metrics, such as PK, SPL, and SEL, are commonly used to evaluate noise and its effects on marine life (see Appendix A.3). In this report, the duration of the SEL accumulation is integrated over the operational time periods for each vessel, in this case 24 hours.

Appropriate subscripts indicate any applied frequency weighting (Appendix A.3.3). The acoustic metrics in this report reflect the updated ANSI and ISO standards for acoustic terminology, ANSI S1.1 (R2013) and ISO 18405:2017 (2017).

This study applies the following noise criteria (Sections 2.1–2.2 and Appendix A.3.1), chosen for their acceptance by regulatory agencies and because they represent current best available science:

- Frequency-weighted accumulated sound exposure levels (SEL; $L_{\mathrm{E,24h}}$) from NMFS (2018) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals. This criteria was applied for consistency with previous work (McPherson et al. 2019, Green et al. 2022).
- Marine mammal behavioural threshold based on the current interim U.S. National Oceanic and Atmospheric Administration (NOAA 2019) criterion for marine mammals of 120 dB re 1 µPa SPL (L_{p}) for non-impulsive sound sources. This is identical to the previously applied behavioural response threshold, however the reference has been updated.
- Sound exposure guidelines for fish, fish eggs, and larvae (Popper et al. 2014).
- Frequency-weighted accumulated sound exposure levels (SEL; $L_{\mathrm{E,24h}}$) from Finneran et al. (2017) for the onset of permanent threshold shift (PTS) and temporary threshold shift (TTS) in sea turtles.

2.1. Marine Mammals

The criteria applied in this study to assess possible effects of non-impulsive sources on marine mammals are summarised in Table 8; Cetaceans (low-, mid-, and high-frequency) were identified as the hearing groups requiring assessment. Details on thresholds related to auditory threshold shifts or hearing loss and behavioural response are provided in Appendix A.3, with frequency weighting explained in detail in Appendix A.3.3. Of particular note, whilst the newly published Southall et al. (2021) provides recommendations and discusses the nuances of assessing behavioural response, the authors do not recommend new numerical thresholds for onset of behavioural responses for marine mammals.

Table 8. Criteria for effects of non-impulsive noise exposure, including vessel noise on marine mammals: SPL and Weighted SEL_{24h} thresholds.

Hearing group	NOAA (2019)	NMFS (2018)	
	Behaviour	PTS onset thresholds (received level)	TTS onset thresholds (received level)
	SPL (L_p; dB re 1 µPa)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)
LF cetaceans	120	199	179
MF cetaceans		198	178
HF cetaceans		173	153

L_p denotes sound pressure level period and has a reference value of 1 µPa.
L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^{2}s.

2.2. Fish, Sea Turtles, Fish Eggs, and Fish Larvae

In 2006, the Working Group on the Effects of Sound on Fish and Turtles was formed to continue developing noise exposure criteria for fish and sea turtles based on work began by a NOAA panel two years earlier. The Working Group developed guidelines with specific thresholds for different levels of effects for several species groups (Popper et al. 2014). The guidelines define quantitative thresholds for three types of immediate effects:

- Mortality, including injury leading to death.
- Recoverable injury, including injuries unlikely to result in mortality, such as hair cell damage and minor haematoma.
- TTS.

Masking and behavioural effects can be assessed qualitatively, by assessing relative risk rather than by specific sound level thresholds. However, as these depend upon activity-based subjective ranges, these effects are not addressed in this report, and are included in Table 9 for completeness only. Because the presence or absence of a swim bladder has a role in hearing, fish susceptibility to injury from noise exposure depends on the species and the presence and possible role of a swim bladder in hearing. Thus, different thresholds were proposed for fish without a swim bladder (also appropriate for sharks and applied to whale sharks in the absence of other information), fish with a swim bladder not used for hearing, and fish that use their swim bladders for hearing. Sea turtles, fish eggs, and fish larvae are considered separately.

Table 9 lists the relevant effects thresholds from Popper et al. (2014) for shipping and non-impulsive noise. Some evidence suggests that fish sensitive to acoustic pressure show a recoverable loss in hearing sensitivity, or injury when exposed to high levels of noise (Scholik and Yan 2002, Amoser and Ladich 2003, Smith et al. 2006); this is reflected in the SPL thresholds for fish with a swim bladder involved in hearing. Finneran et al. (2017) presented revised thresholds for turtle injury, considering frequency weighted SEL, which have been applied in this study (Table 10).

Table 9. Criteria for vessel noise exposure for fish, adapted from Popper et al. (2014).

Type of animal	Mortality and Potential mortal injury	Impairment			Behaviour
		Recoverable injury	TTS	Masking	
Fish: No swim bladder (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) Moderate (I) Moderate (F) Low
Fish: Swim bladder involved in hearing (primarily pressure detection)	(N) Low (I) Low (F) Low	170 dB SPL for 48 h	158 dB SPL for 12 h	(N) High (I) High (F) High	(N) High (I) Moderate (F) Low
Sea turtles	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) High (I) High (F) Moderate	(N) High (I) Moderate (F) Low
Fish eggs and fish larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) Moderate (I) Moderate (F) Low

Sound pressure level dB re 1 µPa.
Relative risk (high, moderate, low) is given for animals at three ranges from the source defined in relative terms as near (N), intermediate (I), and far (F).

Table 10. Acoustic effects of non-impulsive noise on sea turtles, weighted SEL_{24h}, Finneran et al. (2017).

PTS onset thresholds (received level)	TTS onset thresholds (received level)
Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)	Weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^{2}s)
220	200

L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^{2}s.

3. Methods

This study considers operations occurring at the Torosa fields, including flowline installation at the TRA location, rigid pipelaying on a line terminating at the Gas Export Riser Base (GERB), and operations at the FPSO location. Environmental parameters (bathymetry, sound speed profile and geoacoustics) were taken from McPherson et al. (2019). Details are provided in Appendix C.2.

3.1. Acoustic Source Parameters

3.1.1. Flexible Reel-Lay Vessel

Most of the noise incurred by the operation of the flowline installation vessel will be caused by cavitation from its dynamic positioning (DP) thrusters. Measurements of the similar flexible lay and construction vessel *Deep Orient* detailed in Quijano and McPherson (2021) were used as source levels. The *Deep Orient* is a 135 m long DP2 medium construction vessel with 11,500 kW of installed power. In this study, linear extrapolation was used to generate source levels for frequency bands down to 10 Hz, as shown in Figure 4. The resultant modelled broadband SL for this vessel is 181 dB re 1 µPa.

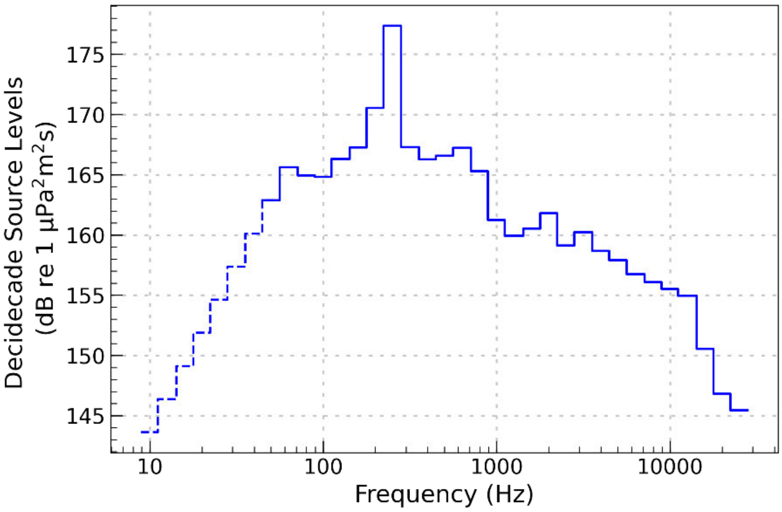

Figure 4. Decidecade band monopole source levels used for Skandi *Hercules*. Measured levels from *Deep Orient*. Frequencies below 50 Hz generated by linear extrapolation from lowest available frequency bands, indicated by dashed line.

3.1.2. Anchor Handling Tugs

Sound source levels for the five tugs involved with FPSO mooring were based on recorded levels for the anchor handling tug *Katun*, recorded whilst performing an anchor pull operation (Hannay et al. 2004). Since anchor handling is a large part of the FPSO mooring operation, these source levels were considered particularly appropriate, as opposed to any recorded source levels of tugs in transit. In this case, recorded levels were not available above 10 kHz, so higher frequencies have been linearly extrapolated from the available data. Figure 5 shows the decidecade band monopole source levels that were used for each tug. These levels resulted in a broadband source level of 184.4 dB re 1 µPa per tug.

Each of these tugs features four main sources of cavitation – two main propellers, forward and aft thrusters. Thruster locations, diameters, and depths were derived by referring to a technical drawing and cross-referencing this with the known length and breadth of the ship. Monopole source depths Z_s were calculated using the following equation, derived from Gray and Greeley (1980):

$$Z_s = Z_{prop} - 0.85 \cdot \varphi_{prop} \tag{1}$$

where Z_{prop} is the depth at the bottom of the propeller and φ_{prop} is the diameter of the propeller. Thus, thruster source depths were determined as 2.34 m, 3.48 m, and 4.03 m for the main propellers, forward, and aft thrusters, respectively. Since these vessels were modelled as single monopole sources, a single source depth of 3.05 m was calculated as the mean of these depths and used for the model.

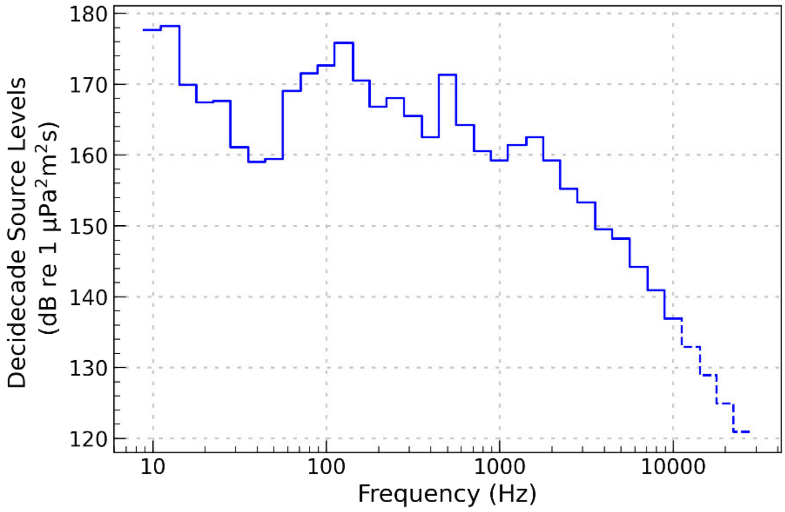

Figure 5. Decidecade band monopole source levels used for tugs involved with FPSO mooring operation. Measured levels from *Katun*. Frequencies above 10 kHz generated by linear extrapolation from highest available frequency bands, indicated by dashed line.

3.1.3. Rigid Pipelay Vessel

The Saipem *Castorone* is a Class 3 pipelay vessel featuring DP, planned for use for rigid pipelaying operations. It has a length of 325 m, a width of 39 m, and a draft of 10.6 m, and features nine thrusters – three tunnel thrusters and six azimuth thrusters. These were each modelled separately as point sources at depths of 1.8 m, 6.1 m, and 11.8 m, which were determined in reference to vessel schematics and following Equation 1. The source level spectra for the individual *Castorone* thrusters were based on 50% power predictions provided by the BJV, and are shown in Figure 6, this matches the consideration of the vessel in Connell et al. (2022). The resultant broadband energy source level (ESL), accounting for all thrusters, is 189.8 dB re 1 µPa; this ESL was not used in the modelling, but is provided for reference only.

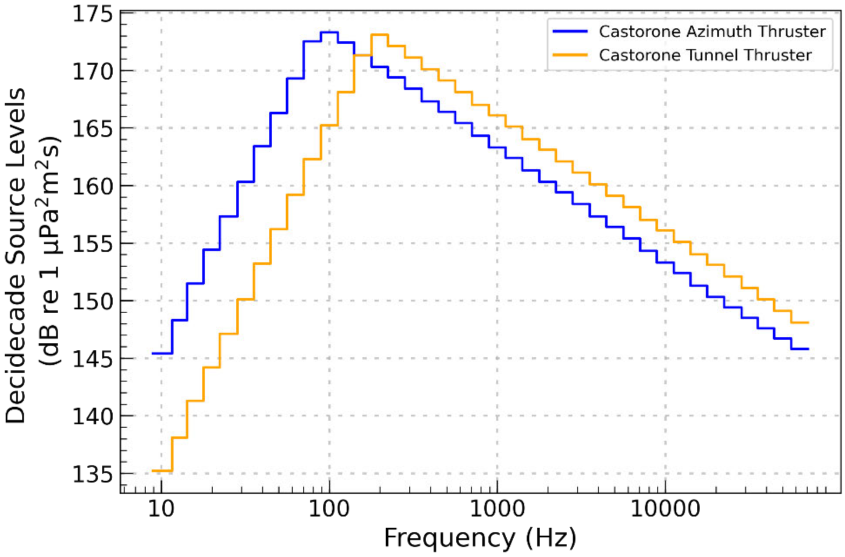

Figure 6. Decidecade band monopole source levels used for Saipem *Castorone*. Levels representative of thrusters operating at 50% power.

3.1.4. B-type Vessel

The B-type vessel will operate next to the *Castorone* in the final line pipe resupply location. It has a length of 141 m, a width of 25 m, and a draft of 8.92 m. The B-type vessel features six thrusters – four tunnel and two azimuth. These were modelled separately as point sources at depths of 6.7 m and 7.2 m for the forward and aft tunnel thrusters, respectively, and 6.9 m for both azimuth thrusters. Depths were again determined following Equation 1. Source level spectra for the two types of thrusters used in the B-type were based on levels provided by the BJV, representative of 40% power matching the consideration of the vessel in Connell et al. (2022), these are shown in Figure 7. In this case, the broadband ESL is 185.7 dB re 1 µPa; this ESL was not used in the modelling, but is provided for reference only.

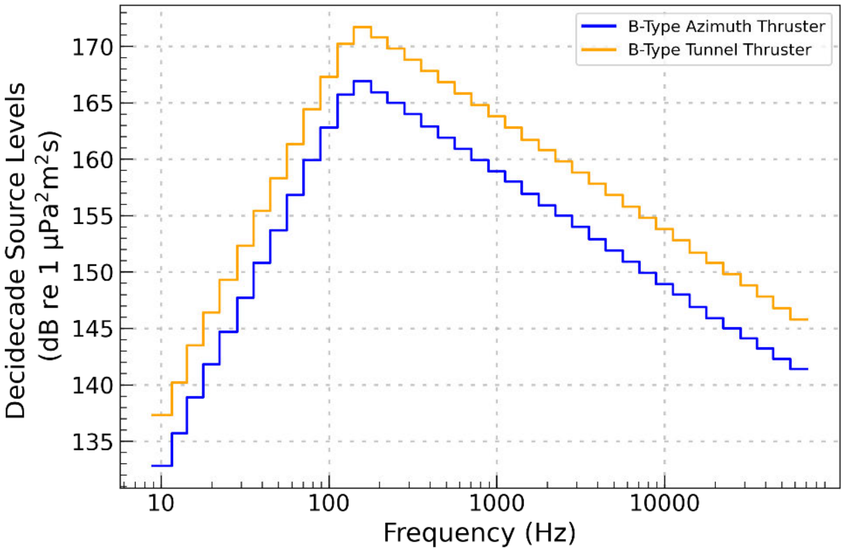

Figure 7. Decidecade band monopole source levels used for B-type vessel. Levels representative of thrusters operating at 40% power.

3.1.5. Offshore Support Vessel

Sound source levels for the OSV were based on the *Fugro Etive*, a general purpose vessel 92.95 m in length, and 19.7 m in breadth, featuring two stern azipull thrusters (Rolls-Royce AZP100), two bow controllable pitch thrusters (Rolls-Royce TT 2200 DPN), and a retractable azimuthing thruster (Rolls-Royce UL1201). The azipull thrusters are primarily used for propulsion, as opposed to the bow/retractable thrusters which are primarily used for dynamic positioning. During OSV resupply, the propulsion thrusters are typically used less than the dynamic positioning. Each thruster was modelled as an individual source based on levels provided by the BJV. These are representative of the bow and retractable thrusters operating at 40% capacity and the stern azipull thrusters operating at 20%; levels are shown in Figure 8. The overall broadband ESL is 181.3 dB re 1 µPa; this ESL was not used in the modelling, but is provided for reference only.

Thruster locations, diameters, and depths were derived by referring to a technical drawing and cross-referencing this with the known length and breadth of the ship, again with reference to Equation 1. Thus, depths of 3.2 m, 6.4 m, and 3.4 m were used for the AZP100, UL1201, and CP thrusters, respectively.

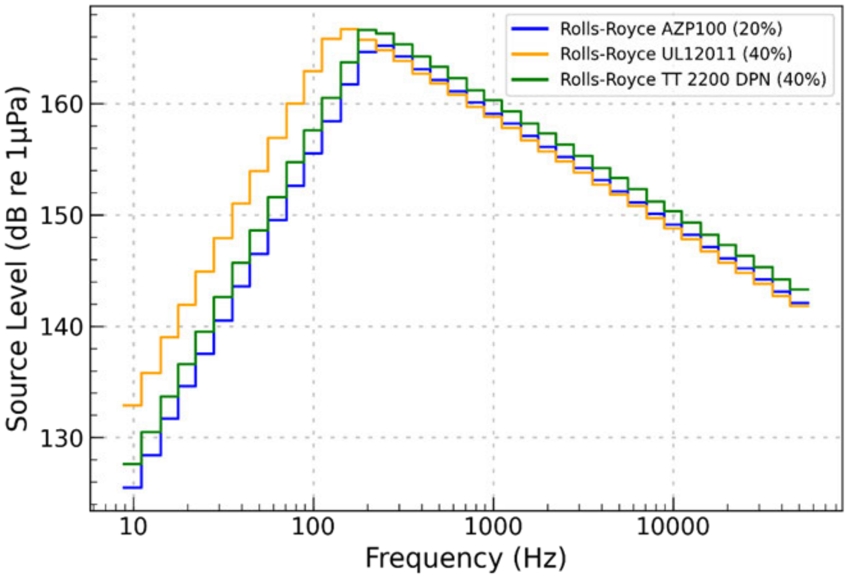

Figure 8. Decidecade band monopole source levels for OSV thruster sources during FPSO resupply. These spectra represent thrusters working at 20 and 40% capacity.

3.1.6. Floating Production, Storage, and Offloading (FPSO) Facility

The proposed FPSO facility is a permanently moored, heading controlled production vessel approximately 370 m long and 67 m wide with a draft of 16 m. While in heading control mode, it operates on two stern thrusters positioned laterally on the keel at the stern of the ship 6 m apart.

The major sources of noise from this vessel are the two thrusters and noise associated with pumps, generators, and other machinery within the vessel. As a proxy for the latter noise source, an average of two source levels measured by Erbe et al. (2013) from the FPSO facilities *Nganhurra* and the *Ngujima Yin*, with a broadband source level of 173.9 dB re 1 µPa, was used. The thrusters were modelled as two separate point sources using theoretical source level spectra for 3000 mm nozzled 4 bladed fixed pitch propellers (FPPs), provided by the BJV. These had a broadband source level of 179.5 dB re 1 µPa.

In combination, the machinery noise and two thruster sources reach a broadband source level of 183 dB re 1 µPa. A future design target for the FPSO is a broadband source level of 178 dB re 1 µPa.

Given the input spectra, it was calculated that a broadband reduction of 6.6 dB per thruster would be required to reach this target. An offset of −6.6 dB was therefore applied to the thruster spectrum for this additional hypothetical scenario. Figure 9 shows the source spectra for machinery and thrusters with and without the level reduction applied. It can be seen that a broadband reduction of thruster level would have greatest impact in terms of exceeding the machinery noise at frequencies of 80 Hz and above.

Machinery noise was modelled as a point source at the planar centre of the vessel at a depth of 8 m, which is 50% of the draught, consistent with the approach taken in McPherson et al. (2019). The thrusters were modelled as two separate point sources positioned 6 m apart at the stern of the ship (relative to the position of the machinery source) at a depth of 16.5 m, specified by the BJV.

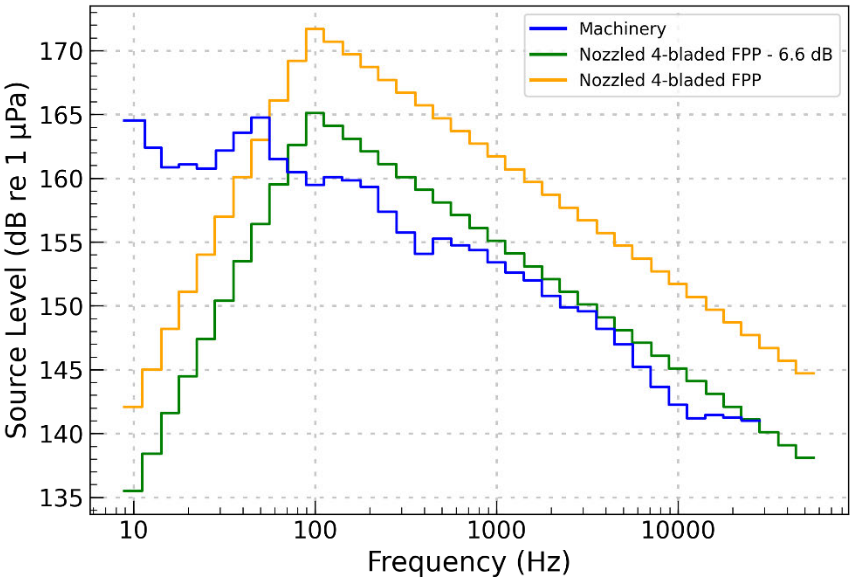

Figure 9. Source levels used for FPSO facility

3.2. Modelling Sound Propagation

JASCO’s combined Marine Operations Noise Model (MONM) and gaussian beam acoustic ray-trace model (BELLHOP) were used to predict the acoustic field at frequencies from 10 Hz to 63 kHz. Details on these models are included in Appendix B.1.

Accumulated SEL was calculated using the following equation:

$$L_{E,24h} = L_E + 10\log_{10}(T) \tag{2}$$

where L_E is the per-second energy source level (output by MONM-BELLHOP) and T is the total number of operational seconds in a 24-hour period.

In the modelled scenarios all vessels are considered to be in continuous operation. Using Equation 2, constant operation over 24 hours yields an offset of 49.3 dB. This offset was applied to the relevant received levels to calculate metrics related to SEL.

4. Results

Sound field results for all scenarios are presented in this section as tables and maps showing propagation ranges and isopleths with relevant effect thresholds. Maximum-over-depth SPL results are presented in Tables 11 to 18 and Figures 10 to 17, while accumulated SEL results are presented in Tables 19 to 22 and Figures 18 to 25.

4.1. Tables

Table 11. *TRA Flexible Reel-Lay, SPL*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) to sound pressure level (SPL) from the centroids of the vessels involved.

SPL (L_p; dB re 1 µPa)	R_{max} (km)	$R_{95\%}$ (km)
180	—	—
170	—	—
160	—	—
150	0.05	0.05
140	0.17	0.17
130	0.55	0.53
120[a]	2.16	2.06
110	10.83	6.71

[a] Threshold for marine mammal behavioural response to non-impulsive noise (NOAA 2019).
A dash indicates the level was not reached within the resolution of the model.

Table 12. *FPSO Mooring, SPL*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) to sound pressure level (SPL) from the centroids of the vessels involved.

SPL (L_p; dB re 1 µPa)	R_{max} (km)	$R_{95\%}$ (km)
180	<0.05	<0.05
170	<0.05	<0.05
160	<0.05	<0.05
150	<0.05	<0.05
140	0.14	0.13
130	0.96	0.76
120[a]	2.44	2.20
110	22.55	18.97

[a] Threshold for marine mammal behavioural response to non-impulsive noise (NOAA 2019).

Table 13. *Rigid Pipelay, SPL*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) to sound pressure level (SPL) from the centroids of the vessels involved. Scenario descriptions are given in Table 7.

SPL (L_p; dB re 1 µPa)	Final Linepipe Resupply		Mid-Point		Gas Export Riser Base	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
180	<0.05	<0.05	—	—	<0.05	<0.05
170	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
160	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
150	0.15	0.14	0.11	0.11	0.12	0.10
140	0.56	0.52	0.49	0.45	0.50	0.45
130	2.52	2.39	2.31	2.17	2.31	2.16
120[a]	9.85	7.64	8.30	6.88	9.40	7.05
110	24.55	18.77	20.66	17.53	21.26	18.07

[a] Threshold for marine mammal behavioural response to non-impulsive noise (NOAA 2019).
A dash indicates the level was not reached.

Table 14. *FPSO, SPL:* Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) to sound pressure level (SPL) from the centroids of the vessels involved. Scenario descriptions are given in Table 7.

SPL (L_p; dB re 1 µPa)	OSV Resupply		FPSO (Heading Control), OSV		FPSO (Optimised Heading Control), OSV	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
180	—	—	—	—	—	—
170	—	—	0.19	0.19	—	—
160	<0.05	<0.05	0.19	0.19	0.19	0.19
150	0.06	0.06	0.24	0.24	0.19	0.10
140	0.17	0.16	0.40	0.35	0.26	0.24
130	0.56	0.52	0.97	0.90	0.64	0.59
120[a]	2.29	2.20	3.92	3.60	2.54	2.43
110	9.27	6.57	13.91	10.89	9.34	7.78

[a] Threshold for marine mammal behavioural response to non-impulsive noise (NOAA 2019).
A dash indicates the level was not reached within the resolution of the model.

Table 15. *TRA Flexible Reel Lay, SPL, fish effect thresholds*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from the vessels to modelled maximum-over-depth sound pressure level (SPL) thresholds based on the quantifiable thresholds for fish with a swim bladder involved in hearing (Popper et al. 2014). Scenario descriptions are given in Table 7.

SPL (L_p; dB re 1 µPa)	R_{max} (km)	$R_{95\%}$ (km)
170[a]	—	—
158[b]	<0.05	<0.05

[a] Recoverable injury (Popper et al. 2014)
[b] TTS
A dash indicates the level was not reached within the resolution of the model.

Table 16. *FPSO Mooring, SPL, fish effect thresholds*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from the vessels to modelled maximum-over-depth sound pressure level (SPL) thresholds based on the quantifiable thresholds for fish with a swim bladder involved in hearing (Popper et al. 2014). Scenario descriptions are given in Table 7.

SPL (L_p; dB re 1 µPa)	R_{max} (km)	$R_{95\%}$ (km)
170[a]	<0.05	<0.05
158[b]	<0.05	<0.05

[a] Recoverable injury (Popper et al. 2014)
[b] TTS

Table 17. *Rigid Pipelay, SPL, fish effect thresholds*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from the vessels to modelled maximum-over-depth sound pressure level (SPL) thresholds based on the quantifiable thresholds for fish with a swim bladder involved in hearing (Popper et al. 2014). Scenario descriptions are given in Table 7.

SPL (L_p; dB re 1 µPa)	Final Linepipe Resupply		Mid-Point		Gas Export Riser Base	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
170[a]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
158[b]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

[a] Recoverable injury (Popper et al. 2014)
[b] TTS

Table 18. *FPSO, SPL, fish effect thresholds*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from the vessels to modelled maximum-over-depth sound pressure level (SPL) thresholds based on the quantifiable thresholds for fish with a swim bladder involved in hearing (Popper et al. 2014). Scenario descriptions are given in Table 7.

SPL (L_p; dB re 1 µPa)	OSV Resupply		FPSO (Heading Control), OSV		FPSO (Optimised Heading Control), OSV	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
170[a]	—	—	0.19	0.19	—	—
158[b]	<0.05	<0.05	0.19	0.19	0.19	0.19

[a] Recoverable injury (Popper et al. 2014)
[b] TTS
A dash indicates the level was not reached.

Table 19. *TRA Flexible Reel Lay, SEL$_{24h}$*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from the vessels to modelled maximum-over-depth frequency-weighted SEL$_{24h}$ permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds for marine mammals (NMFS 2018) and sea turtles (Finneran et al. 2017). Scenario descriptions are given in Table 7.

Hearing group	Threshold for SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa²s)[a]	R_{max} (km)	$R_{95\%}$ (km)
PTS			
LF cetaceans	199	<0.05	<0.05
MF cetaceans	198	—	—
HF cetaceans	173	<0.05	<0.05
Sea turtles	220	—	—
TTS			
LF cetaceans	179	0.46	0.45
MF cetaceans	178	<0.05	<0.05
HF cetaceans	153	0.90	0.88
Sea turtles	200	<0.05	<0.05

[a] Frequency weighted.
A dash indicates the level was not reached.

Table 20. *FPSO Mooring, SEL_{24h}*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from the vessels to modelled maximum-over-depth frequency-weighted SEL_{24h} permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds for marine mammals (NMFS 2018) and sea turtles (Finneran et al. 2017). Scenario descriptions are given in Table 7.

Hearing group	Threshold for SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²s)[a]	R_{max} (km)	$R_{95\%}$ (km)
PTS			
LF cetaceans	199	<0.05	<0.05
MF cetaceans	198	—	—
HF cetaceans	173	<0.05	<0.05
Sea turtles	220	<0.05	<0.05
TTS			
LF cetaceans	179	0.53	0.36
MF cetaceans	178	<0.05	<0.05
HF cetaceans	153	0.13	0.12
Sea turtles	200	<0.05	<0.05

[a] Frequency weighted.

A dash indicates the level was not reached.

Table 21. *Rigid Pipelay, SEL_{24h}*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from the vessels to modelled maximum-over-depth frequency-weighted SEL_{24h} permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds for marine mammals (NMFS 2018) and sea turtles (Finneran et al. 2017). Scenario descriptions are given in Table 7.

Hearing group	Threshold for SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²s)[a]	Final Linepipe Resupply		Mid-Point		Gas Export Riser Base	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
		PTS					
LF cetaceans	199	0.10	0.09	0.08	0.08	0.07	0.07
MF cetaceans	198	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
HF cetaceans	173	0.20	0.18	0.15	0.14	0.15	0.15
Sea turtles	220	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
		TTS					
LF cetaceans	179	2.16	2.05	1.82	1.70	1.82	1.70
MF cetaceans	178	0.12	0.12	0.10	0.09	0.11	0.10
HF cetaceans	153	2.96	2.80	2.85	2.72	2.86	2.72
Sea turtles	200	0.10	0.10	0.08	0.08	0.08	0.07

[a] Frequency weighted.

A dash indicates the level was not reached.

Table 22. *FPSO, SEL$_{24h}$*: Maximum (R_{max}) and 95% ($R_{95\%}$) horizontal distances (in km) from the vessels to modelled maximum-over-depth frequency-weighted SEL$_{24h}$ permanent threshold shift (PTS) and temporary threshold shift (TTS) thresholds for marine mammals (NMFS 2018) and sea turtles (Finneran et al. 2017). Scenario descriptions are given in Table 7.

Hearing group	Threshold for SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa²s)[a]	FPSO (Machinery Only), OSV		FPSO (Heading Control), OSV		FPSO (Optimised Heading Control), OSV	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
PTS							
LF cetaceans	199	0.06	0.06	0.20	0.20	0.19	0.19
MF cetaceans	198	—	—	0.19	0.19	—	—
HF cetaceans	173	0.06	0.06	0.25	0.24	0.20	0.20
Sea turtles	220	—	—	—	—	—	—
TTS							
LF cetaceans	179	0.47	0.45	0.71	0.65	0.52	0.49
MF cetaceans	178	0.06	0.06	0.20	0.20	0.19	0.19
HF cetaceans	153	1.00	0.96	1.19	1.14	1.03	1.00
Sea turtles	200	0.06	0.06	0.20	0.20	0.19	0.19

[a] Frequency weighted.

A dash indicates the level was not reached.

4.2. Maps

4.2.1. Maximum-over-depth SPL Sound Fields

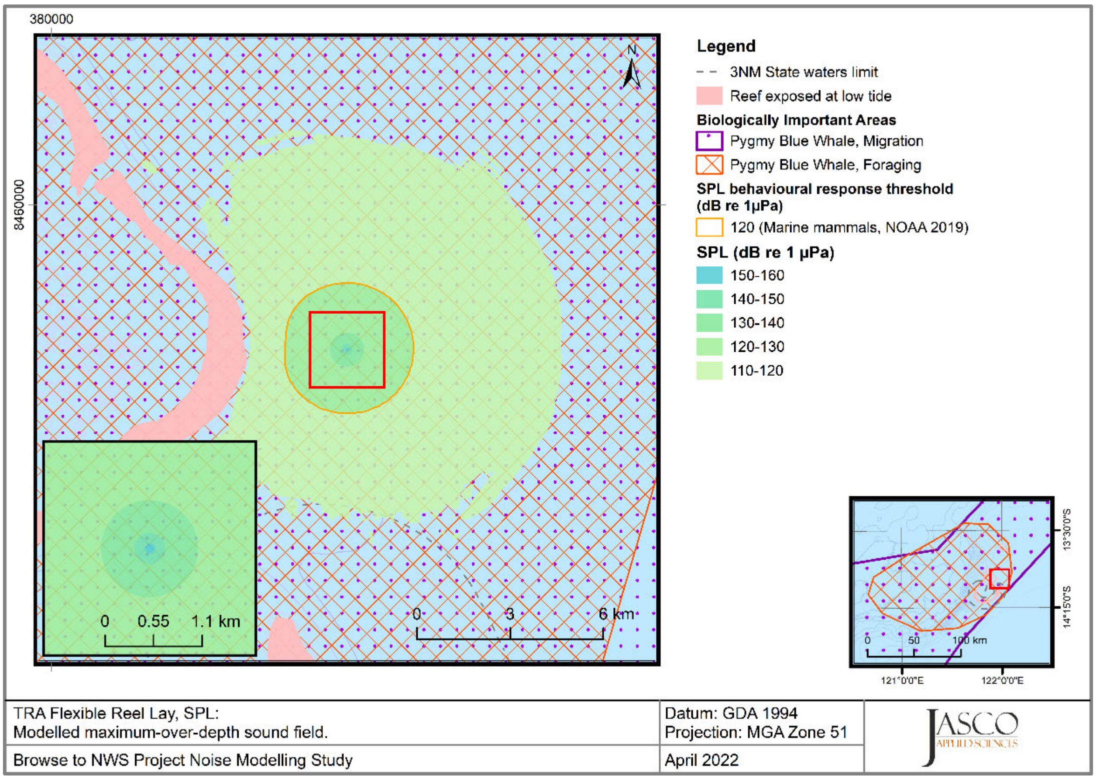

Figure 10. *TRA Flexible Reel Lay, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

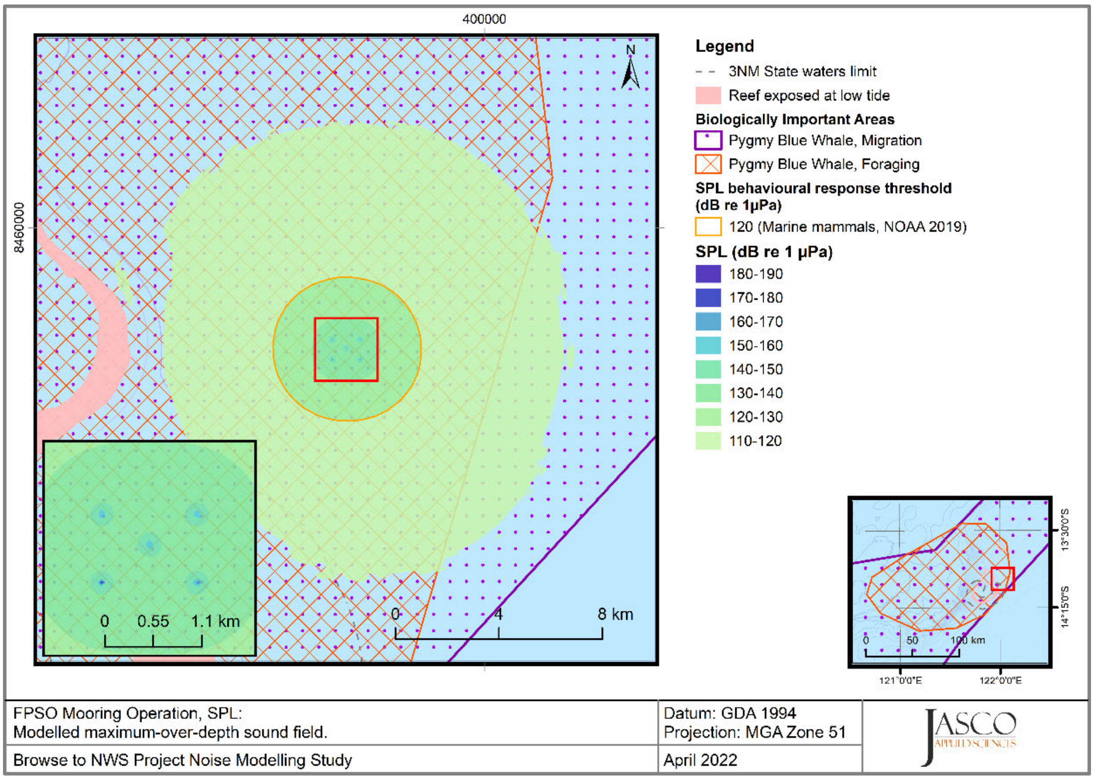

Figure 11. *FPSO Mooring, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

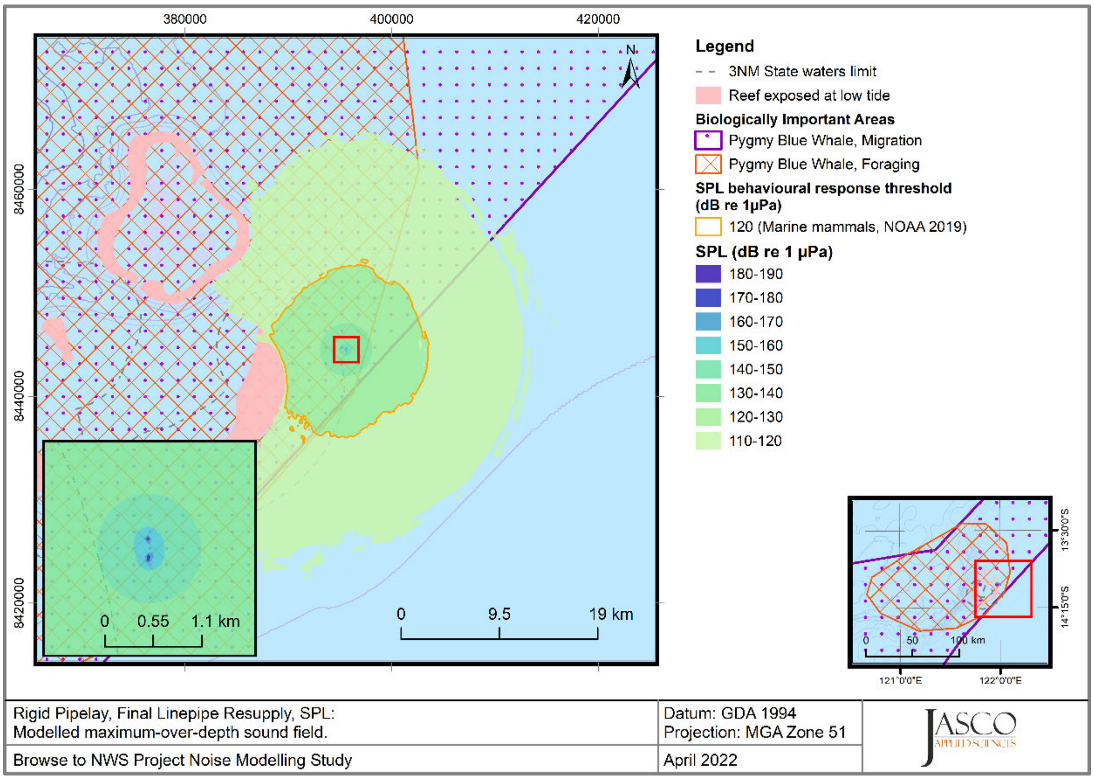

Figure 12. *Rigid Pipelay, Final Linepipe Resupply, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

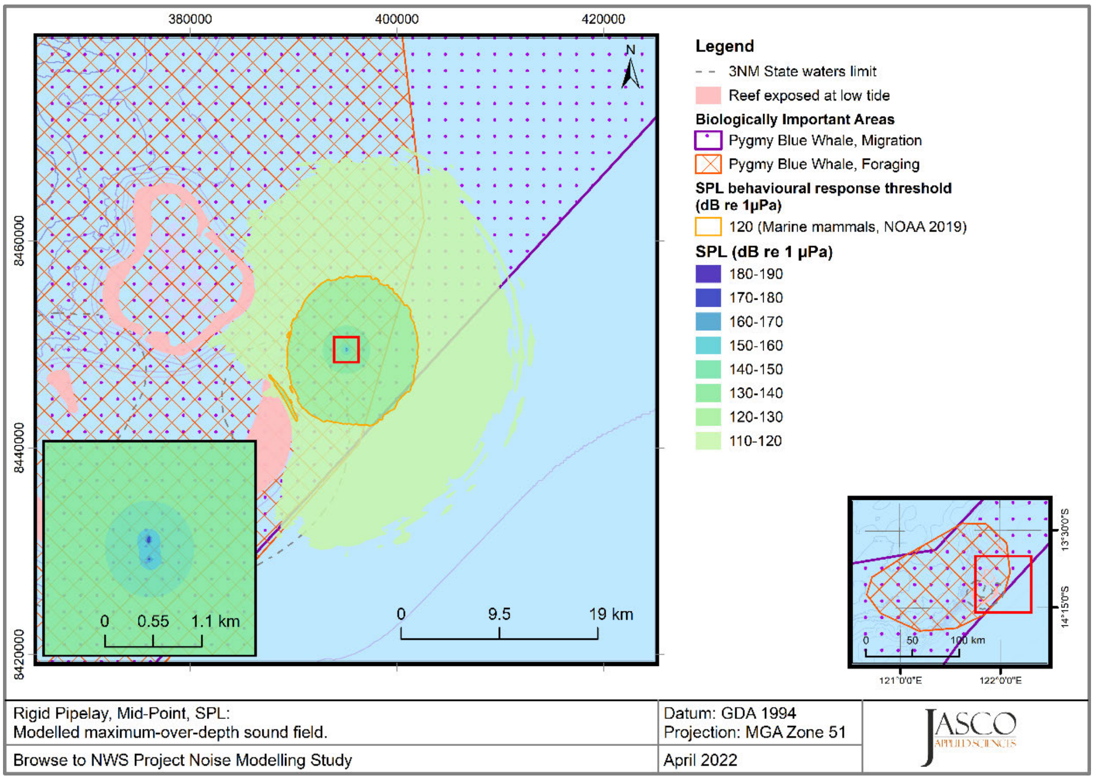

Figure 13. *Rigid Pipelay, Mid-Point, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

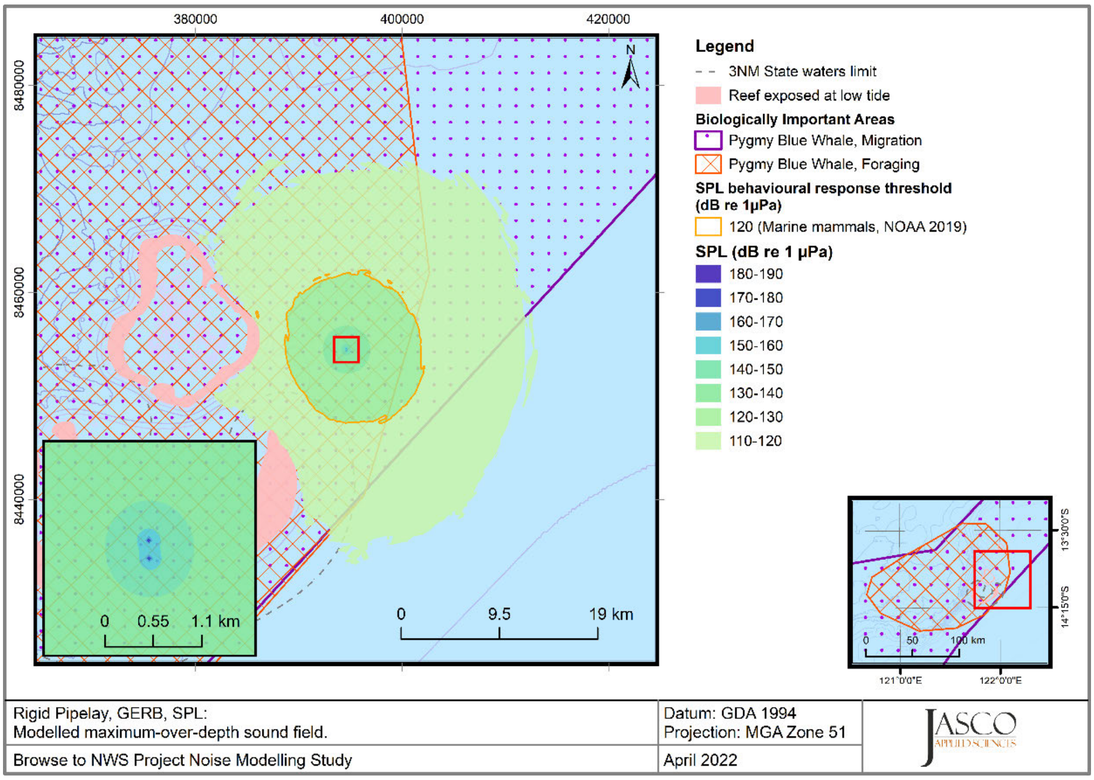

Figure 14. *Rigid Pipelay, Gas Export Riser Base, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

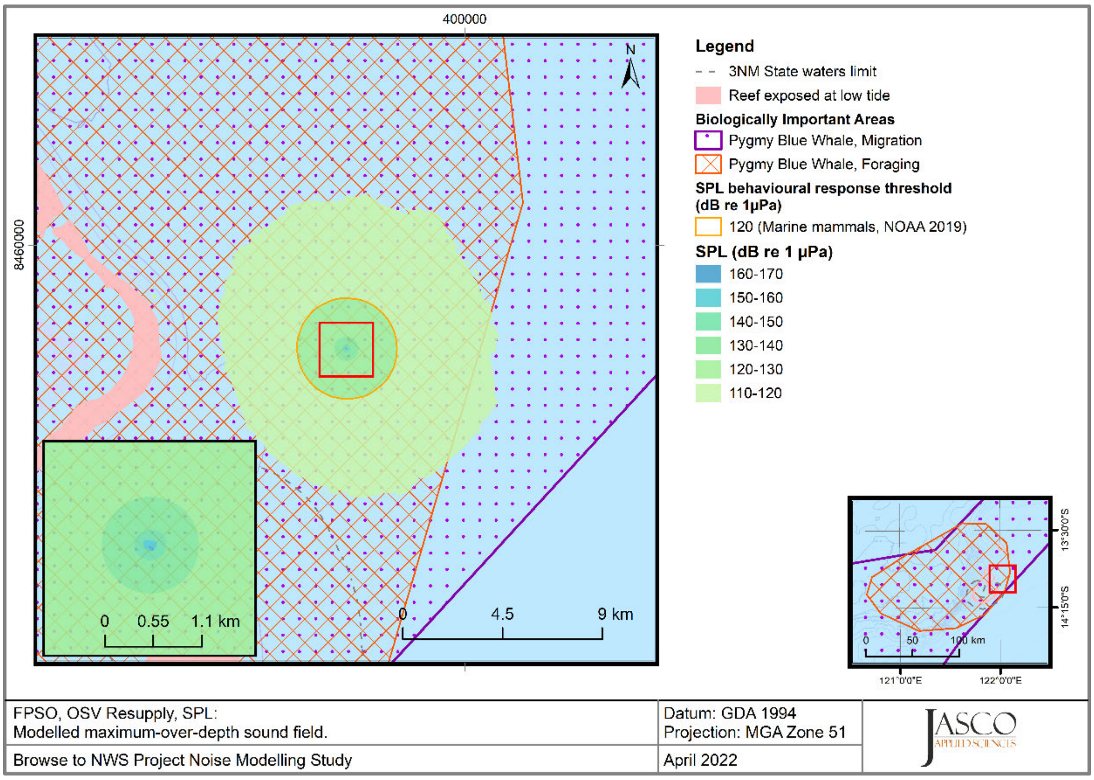

Figure 15. *FPSO, OSV Resupply, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

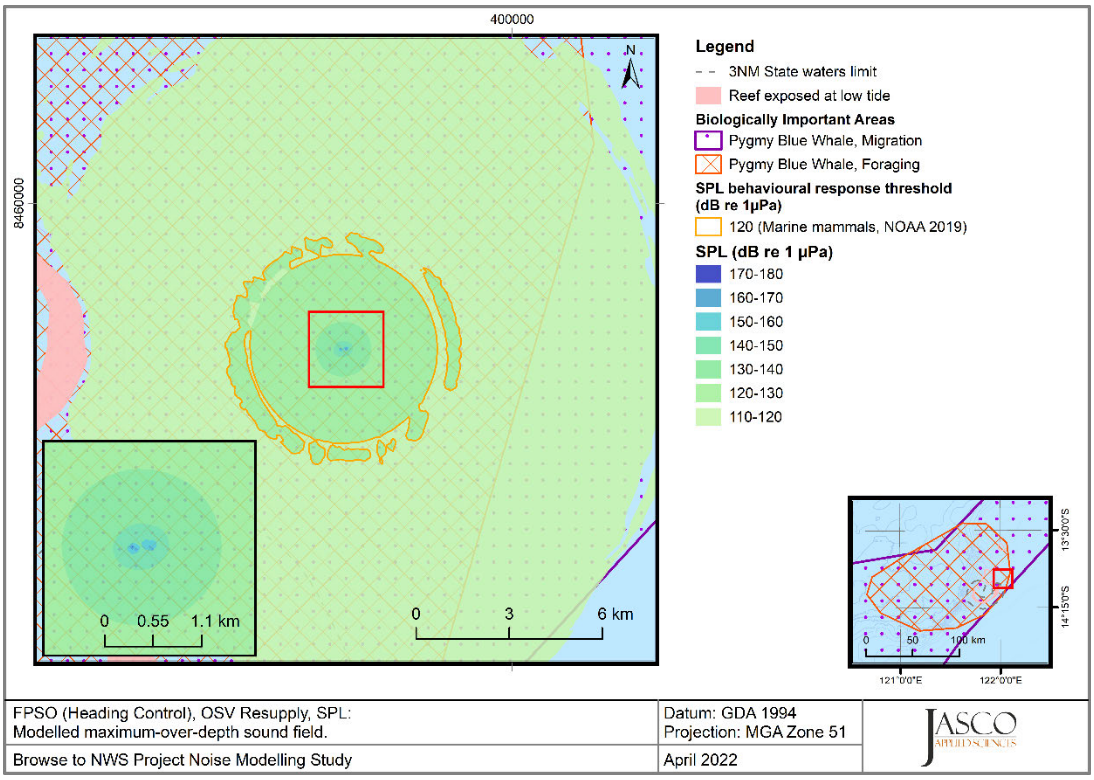

Figure 16. *FPSO (Heading Control), OSV Resupply, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

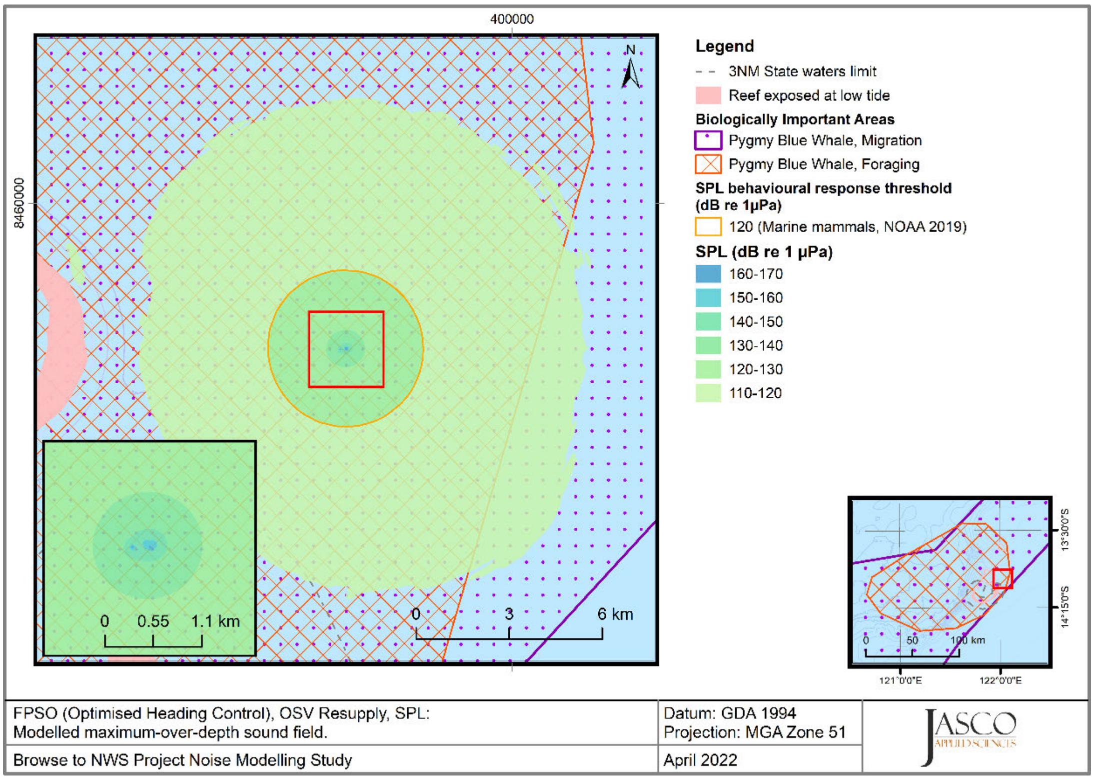

Figure 17. *FPSO (Optimised Heading Control), OSV Resupply, SPL*: Sound level contour map, showing maximum-over-depth results. Isopleth shows marine mammal behavioural criteria (120 dB re 1 µPa).

4.2.2. Accumulated SEL Sound Fields

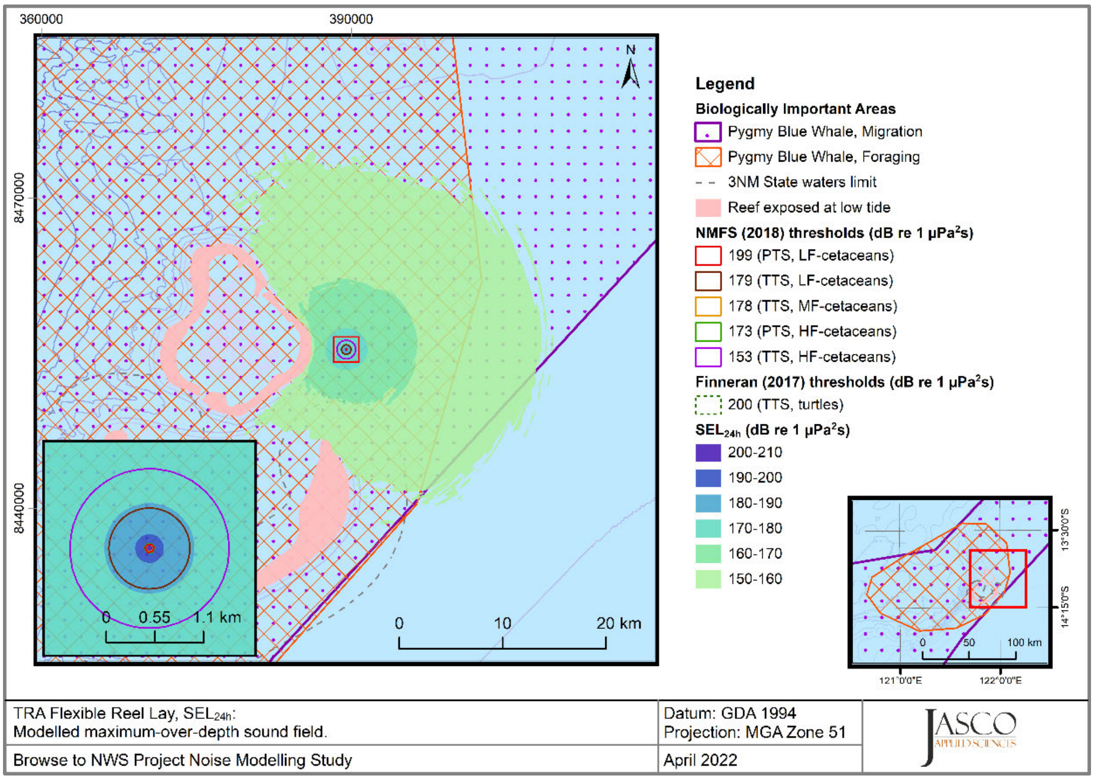

Figure 18. *TRA Flexible Reel Lay, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

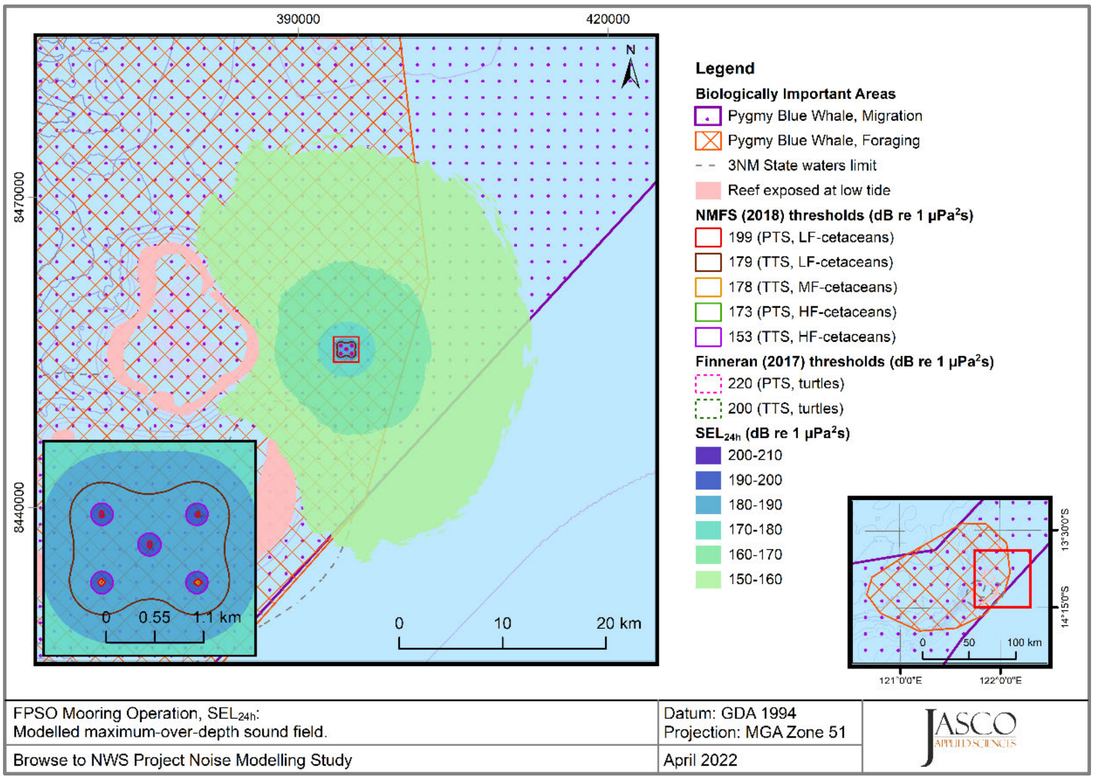

Figure 19. *FPSO Mooring Operation, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

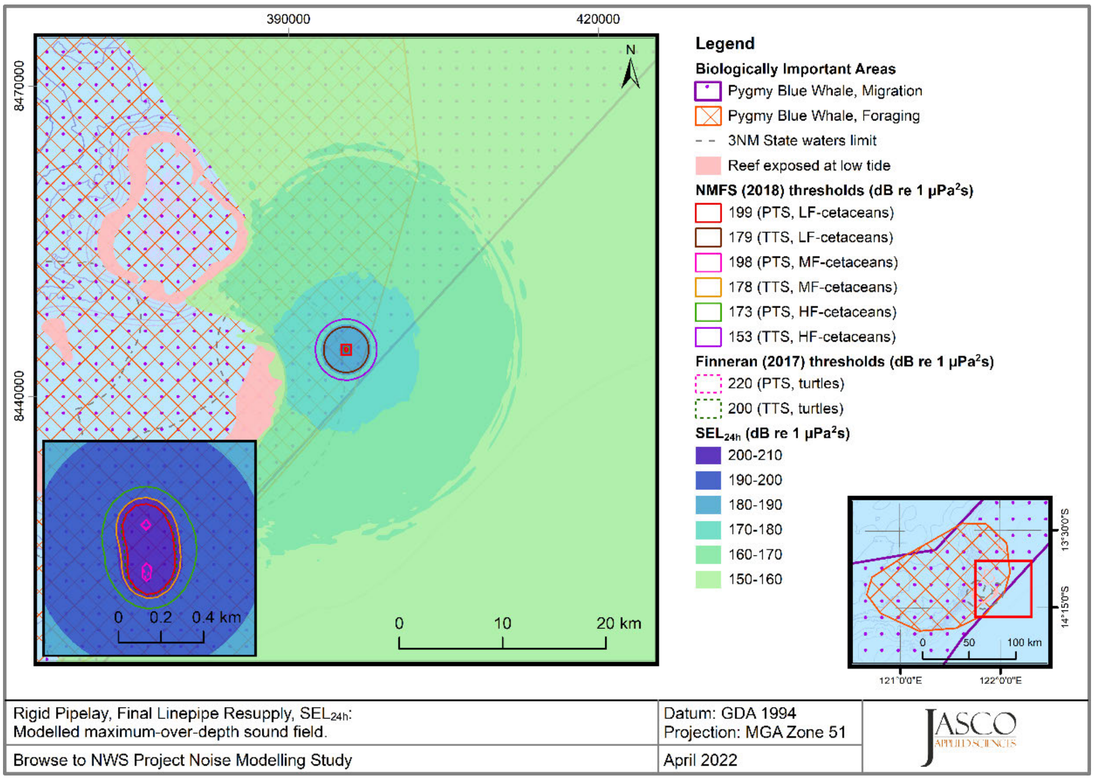

Figure 20. *Rigid Pipelay, Final Linepipe Resupply, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

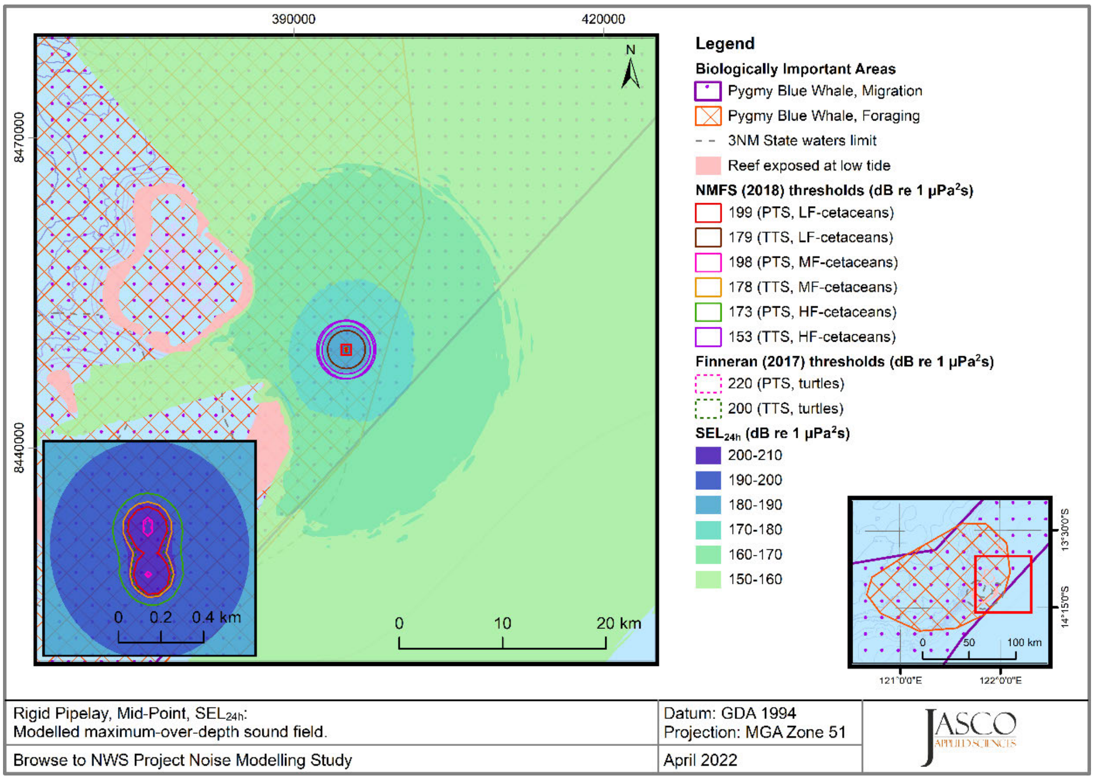

Figure 21. *Rigid Pipelay, Mid-Point, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

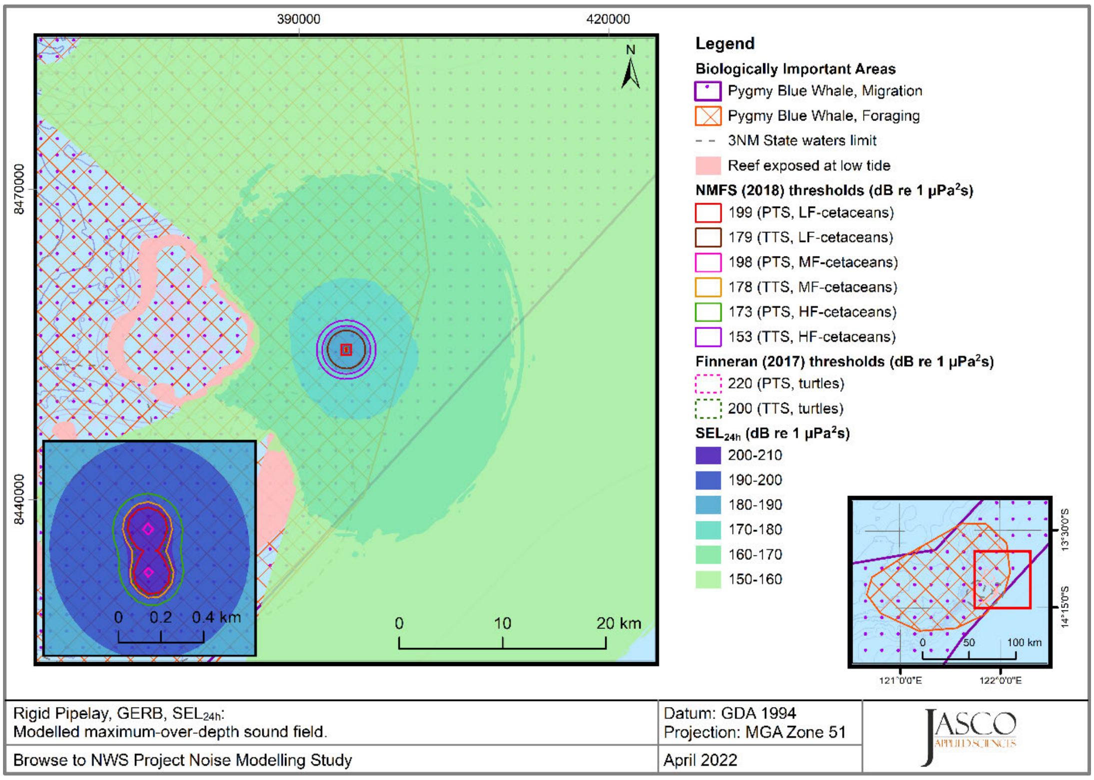

Figure 22. *Rigid Pipelay, Gas Export Riser Base, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

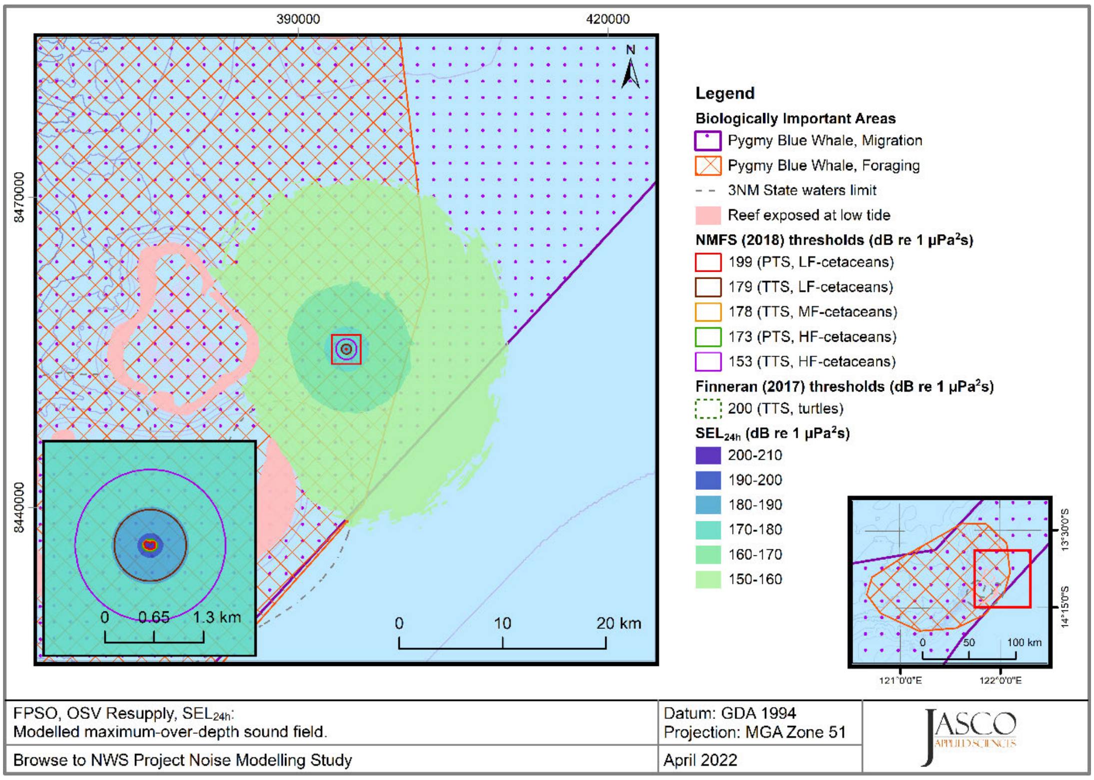

Figure 23. *FPSO, OSV Resupply, SEL_{24h}*: Sound level contour map showing unweighted maximum-over-depth SEL_{24h} results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

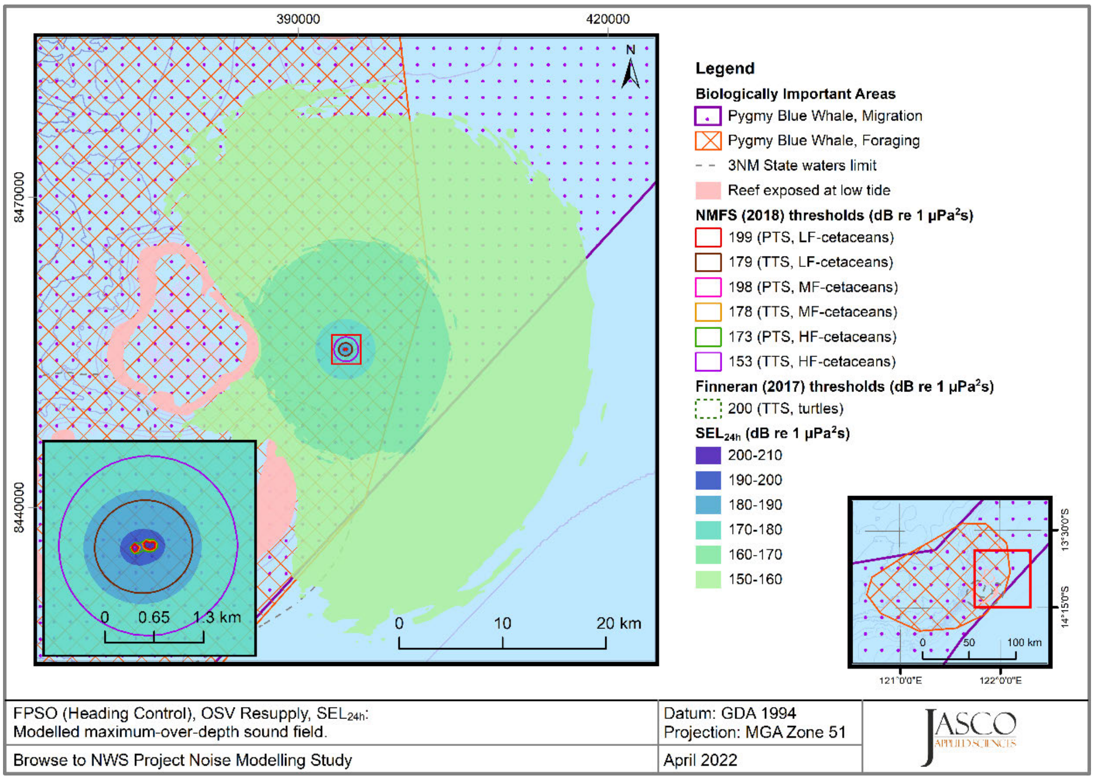

Figure 24. *FPSO (Heading Control), OSV Resupply, SEL_{24h}*: Sound level contour map showing unweighted maximum-over-depth SEL_{24h} results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

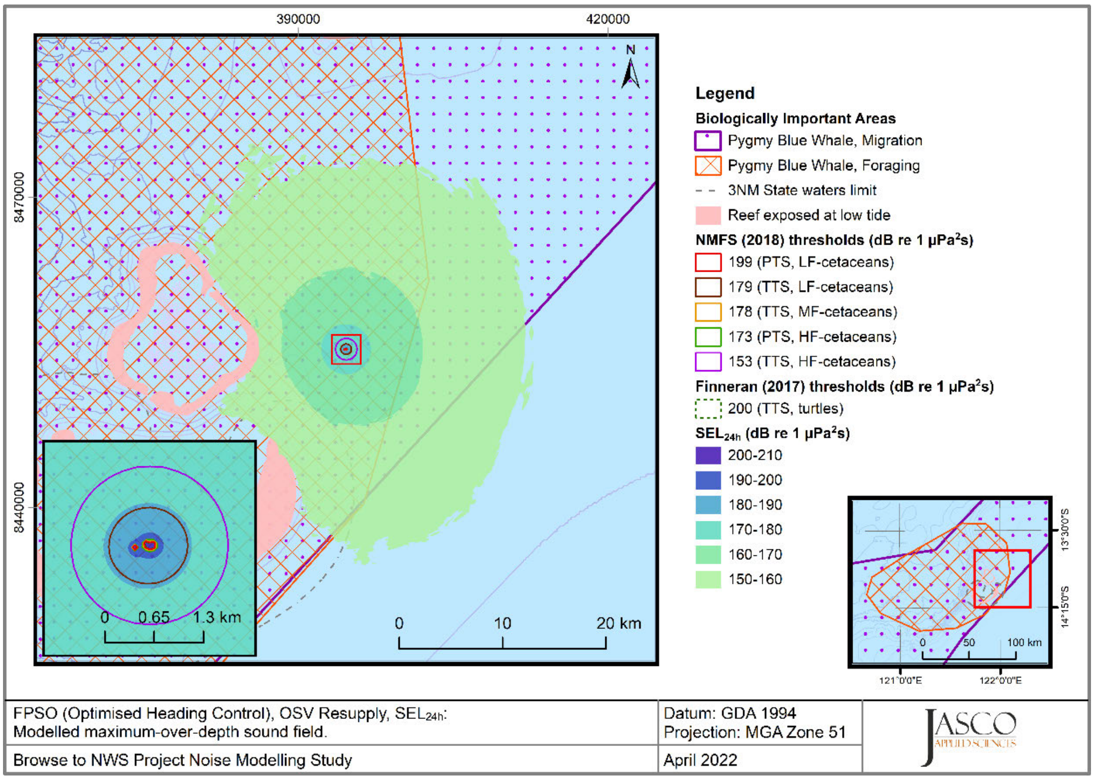

Figure 25. *FPSO (Optimised Heading Control), OSV Resupply, SEL$_{24h}$*: Sound level contour map showing unweighted maximum-over-depth SEL$_{24h}$ results, along with isopleths for PTS and TTS thresholds in low, mid, and high-frequency cetaceans and sea turtles.

5. Discussion

Results have been presented showing the propagation of underwater sound from various vessels, including flexible reel-lay and rigid pipelay vessels, AHTs during an FPSO mooring operation, and an FPSO resupply scenario featuring various levels of heading control and an associated OSV. The rigid pipelay vessel, OSV, and FPSO were modelled using individual thruster sources, whereas the AHTs and flexible reel-lay vessel were modelled using a single representative point source.

The main influence on sound propagation is the bathymetry in the local area. The nearby presence of Scott Reef blocks much of the sound propagation in a westerly direction. This is especially evident for the operations nearest the reef, including the flexible reel-lay and rigid pipelay operations, but somewhat less prevalent in the FPSO resupply scenarios. This is due to the greater distance of this scenario from the reef and generally lower source levels involved. Figures 15–17 show that the reef does not affect propagation from the FPSO resupply scenario at levels of interest for SPL. It should be noted, however, that though in other scenarios the propagation is more influenced by the reef, it is only for the final resupply location of the rigid pipelay vessel that it has any real effect on ranges of interest (see Figure 12). Similarly, it can be seen that although SEL_{24h} levels are visibly affected by the reef from all sites, this does not occur at ranges that affect any relevant thresholds (see Figures 18–25).

Of the three modelled locations for the rigid pipelay scenario, SEL_{24h} threshold distances are largely consistent between the two locations modelled without the attendant B-type vessel (GERB and mid-point), and slightly higher for the final linepipe resupply location with the attendant B-type (see Table 21). This is probably due to the additional sound energy from the B-type vessel but may also be influenced by the somewhat increased water depth at this location. Interestingly, for the SPL distances, R_{max} to 120 dB re 1 µPa is slightly shorter at the mid-point than at GERB, whereas distances to higher SPL levels are very similar (see Table 13). This might be due to the aforementioned influence of the reef on propagation.

Despite the AHTs having a nominally higher broadband monopole source level (Section 3.1.2) than the OSV (Section 3.1.5) and FPSO under heading control (Section 3.1.6), R_{max} distances to the 120 dB re 1 µPa threshold were larger for the FPSO resupply scenario under heading control than for the FPSO mooring scenario. Maximum ranges were 3.92 km for FPSO resupply under heading control (Table 14) compared to 2.44 km for FPSO mooring (Table 12). The main reason for this is that the shallow source depth for each AHT (3.05 m) does not support long-range propagation at the low frequencies which dominate the broadband source level (Figure 5).

Results presented in Table 14 indicate that optimising the FPSO heading control reduces SPL threshold ranges significantly relative to using non-optimised heading control, and brings them close to the modelled ranges where the FPSO is modelled using machinery noise only. For instance, activating heading control increases the range to the 120 dB re 1 µPa threshold by 1.63 km. Using optimised heading control, however, this increase is only 250 m. The effect on SEL_{24h} ranges (Table 22), however, is dependent on the species considered. There is, for instance, very little effect on distances to turtle thresholds, probably due to the fact that turtles have more limited sensitivity to the mid-to-high frequency ranges most affected by optimising the heading control (compare Figure A-3 to Figure 9). There is more of an effect on the TTS ranges for LF cetaceans, which are sensitive to a relatively broad range of frequencies.

Glossary

Unless otherwise stated in an entry, these definitions are consistent with ISO 80000-3 (2017).

absorption

The reduction of acoustic pressure amplitude due to acoustic particle motion energy converting to heat in the propagation medium.

attenuation

The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

auditory frequency weighting

The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2007).

auditory frequency weighting function

Frequency weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity. Example hearing groups are low-, mid-, and high-frequency cetaceans, phocid and otariid pinnipeds.

azimuth

A horizontal angle relative to a reference direction, which is often magnetic north or the direction of travel. In navigation it is also called bearing.

broadband level

The total level measured over a specified frequency range.

cetacean

Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises.

continuous sound

A sound whose sound pressure level remains above ambient sound during the observation period. A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 80000-3:2006).

decidecade

One tenth of a decade. *Note*: An alternative name for decidecade (symbol ddec) is "one-tenth decade". A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a "one-third octave".

decidecade band

Frequency band whose bandwidth is one decidecade. *Note*: The bandwidth of a decidecade band increases with increasing centre frequency.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB.

ensonified

Exposed to sound.

far field

The zone where, to an observer, sound originating from an array of sources (or a spatially distributed source) appears to radiate from a single point.

flat weighting

Term indicating that no frequency weighting function is applied. Synonymous with unweighted.

frequency

The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. 1 Hz is equal to 1 cycle per second.

frequency weighting

The process of applying a frequency weighting function.

frequency-weighting function

The squared magnitude of the sound pressure transfer function. For sound of a given frequency, the frequency weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency weighting function*: compensatory frequency weighting function accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
- *System frequency weighting function*: frequency weighting function describing the sensitivity of an acoustic acquisition system, typically consisting of a hydrophone, one or more amplifiers, and an analogue to digital converter.

geoacoustic

Relating to the acoustic properties of the seabed.

hearing group

Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include very low-frequency (VLF) cetaceans, low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW) (NMFS 2018, Southall et al. 2019). See **auditory frequency weighting functions**, which are often applied to these groups. Examples for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014).

hertz (Hz)

A unit of frequency defined as one cycle per second.

high-frequency (HF) cetacean

See **hearing group**.

isopleth

A line drawn on a map through all points having the same value of some quantity.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level. For example, a value of sound exposure level with reference to 1 μPa^2 s can be written in the form *x* dB re 1 μPa^2 s.

low-frequency (LF) cetacean

See **hearing group**.

mid-frequency (MF) cetacean

See **hearing group**.

monopole source level (MSL)

A source level that has been calculated using an acoustic model that accounts for the effect of the sea-surface and seabed on sound propagation, assuming a point-like (monopole) sound source. Also see **radiated noise level**.

M-weighting

See **auditory frequency weighting function** (as proposed by Southall et al. 2007).

non-impulsive sound

Sound that is not an impulsive sound. A non-impulsive sound is not necessarily a continuous sound.

octave

The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

parabolic equation method

A computationally efficient solution to the acoustic wave equation that is used to model propagation loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of propagation loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

point source

A source that radiates sound as if from a single point.

pressure, acoustic

The deviation from the ambient pressure caused by a sound wave. Also called sound pressure.
Unit: pascal (Pa).

propagation loss (PL)

Difference between a source level (SL) and the level at a specified location, PL(x) = SL − L(x). Also see **transmission loss**.

radiated noise level (RNL)

A source level that has been calculated assuming sound pressure decays geometrically with distance from the source, with no influence of the sea-surface and seabed. Also see **monopole source level**.

received level

The level measured (or that would be measured) at a defined location. The type of level should be specified.

reference values

standard underwater references values used for calculating sound **levels**, e.g., the reference value for expressing sound pressure level in decibels is 1 μPa.

Quantity	Reference value
Sound pressure	1 μPa
Sound exposure	1 μPa^2 s
Sound particle displacement	1 pm
Sound particle velocity	1 nm/s
Sound particle acceleration	1 μm/s^2

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium.

sound exposure

Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 hours) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2 s.

sound exposure level

The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 μPa^2 s.

$$L_E := 10\log_{10}(E/E_0)\,\mathrm{dB} \;= 20\log_{10}\left(E^{1/2}/E_0^{1/2}\right)\,\mathrm{dB}$$

The frequency band and integration time should be specified. Abbreviation: SEL.

sound field

Region containing sound waves.

sound pressure

The contribution to total pressure caused by the action of sound.

sound pressure level (rms sound pressure level)

The level ($L_{p,\mathrm{rms}}$) of the time-mean-square sound pressure (p_{rms}^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2.

$$L_{p,\mathrm{rms}} := 10\log_{10}(p_{\mathrm{rms}}^2/p_0^2)\,\mathrm{dB} \;= 20\log_{10}(p_{\mathrm{rms}}/p_0)\,\mathrm{dB}$$

The frequency band and averaging time should be specified. Abbreviation: SPL or Lrms.

sound speed profile

The speed of sound in the water column as a function of depth below the water surface.

source level (SL)

A property of a sound source obtained by adding to the sound pressure level measured in the far field the propagation loss from the acoustic centre of the source to the receiver position. Unit: decibel (dB). Reference value: 1 $\mu Pa^2 m^2$.

spectrum

An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound exposure distribution with frequency.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity. TTS can be caused by noise exposure.

transmission loss (TL)

The difference between a specified level at one location and that at a different location, TL(x1,x2) = L(x1) − L(x2).

unweighted

Term indicating that no frequency weighting function is applied. Synonymous with flat weighting.

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Appendix A. Underwater Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially pulsed sound such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate sound and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow International Organization for Standardization definitions and symbols for sound metrics (e.g., ISO 2017, ANSI S1.1-2013).

A.1. Acoustic Metrics

The sound pressure level (SPL or L_p; dB re 1 μPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s). It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T g(t)\,p^2(t)\,dt\Big/p_0^2\right)\,\mathrm{dB} \tag{A-1}$$

where $g(t)$ is an optional time weighting function. In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal. For in-air studies, when evaluating the perceived loudness of sounds with rapid amplitude variations in time, the time weighting function $g(t)$ is often set to a decaying exponential function that emphasizes more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. For example, human-based fast time-weighted SPL ($L_{p,fast}$) applies an exponential function with time constant 125 ms. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function of width 125 ms; the results can be referred to as $L_{p,boxcar\ 125ms}$. Another approach, historically used to evaluate SPL of impulsive signals underwater, defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5% and 95% of the cumulative square pressure function encompassing the duration of an impulsive acoustic event. This calculation is applied individually to each impulse signal, and the results have been referred to as 90% SPL ($L_{p,90\%}$).

The sound exposure level (SEL or L_E; dB re 1 μPa^2 s) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_E = 10\log_{10}\left(\int_T p^2(t)\,dt\Big/T_0 p_0^2\right)\,\mathrm{dB} \tag{A-2}$$

where T_0 is a reference time interval of 1 s. SEL continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered for its relevance to impact to the exposed recipients.

SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events. When applied to pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

$$L_{E,N} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}}\right)\ \mathrm{dB} \tag{A-3}$$

Because the SPL(T_{90}) and SEL are both computed from the integral of square pressure, these metrics are related numerically by the following expression, which depends only on the duration of the time window T:

$$L_p = L_E - 10\log_{10}(T) \tag{A-4}$$

$$L_{p90} = L_\mathrm{E} - 10\log_{10}(T_{90}) - 0.458 \tag{A-5}$$

where the 0.458 dB factor accounts for the 10% of pulse SEL missing from the SPL(T_{90}) integration time window.

Energy equivalent SPL (L_{eq}; dB re 1 µPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, $p(t)$, over the same time period, T:

$$L_\mathrm{eq} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)\,dt \Big/ p_0^2\right) \tag{A-6}$$

The equations for SPL and the energy-equivalent SPL are numerically identical. Conceptually, the difference between the two metrics is that the SPL is typically computed over short periods (typically of 1 s or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the L_{eq} reflects the average SPL of an acoustic signal over time periods typically of 1 min to several hours.

A.2. Decidecade Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analysing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are one tenth of a decade wide. A decidecade is sometimes referred to as a "1/3-octave" because one tenth of a decade is approximately equal to one third of an octave. Each decade represents a factor 10 in sound frequency. Each octave represents a factor 2 in sound frequency. The centre frequency of the ith band, $f_\mathrm{c}(i)$, is defined as:

$$f_\mathrm{c}(i) = 10^{\frac{i}{10}}\ \mathrm{kHz} \tag{A-7}$$

and the low (f_lo) and high (f_hi) frequency limits of the ith decade band are defined as:

$$f_{\mathrm{lo},i} = 10^{\frac{-1}{20}} f_\mathrm{c}(i) \quad \text{and} \quad f_{\mathrm{hi},i} = 10^{\frac{1}{20}} f_\mathrm{c}(i) \tag{A-8}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-1). The acoustic modelling spans from band $f_c(1) = 10\ Hz$ to $f_c(37) = 63\ kHz$.

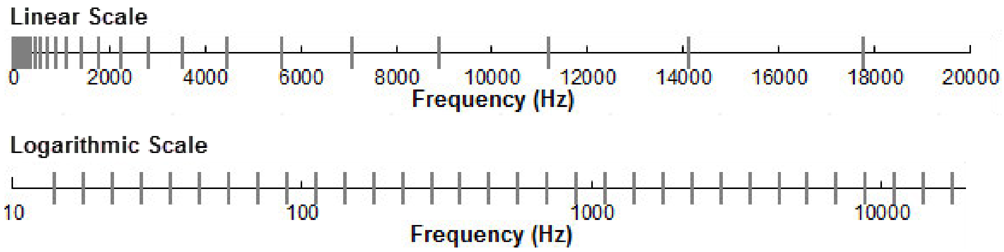

Figure A-1. Decidecade frequency bands (vertical lines) shown on both linear and logarithmic frequency scales

The sound pressure level in the ith band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{\mathrm{lo},i}$ and $f_{\mathrm{hi},i}$:

$$L_{p,i} = 10 \log_{10} \int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\,\mathrm{d}f \;\; \mathrm{dB} \qquad \text{(A-9)}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}} \,\mathrm{dB} \qquad \text{(A-10)}$$

Figure A-2 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient sound signal. Because the decidecade bands are wider than 1 Hz, the decidecade band SPL is higher than the spectral levels at higher frequencies. Acoustic modelling of decidecade bands requires less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

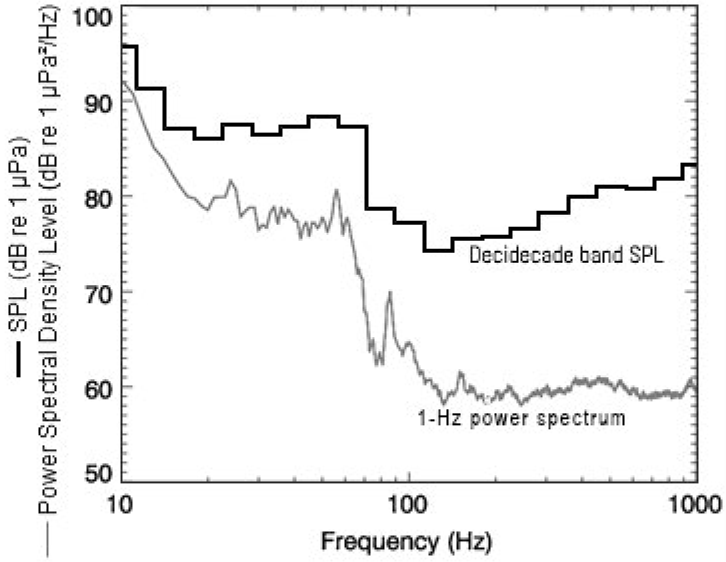

Figure A-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient sound shown on a logarithmic frequency scale. Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the power spectrum.

A.3. Marine Mammal Impact Criteria

It has been long recognised that marine mammals can be adversely affected by underwater anthropogenic noise. For example, Payne and Webb (1971) suggested that communication distances of fin whales are reduced by shipping sounds. Subsequently, similar concerns arose regarding effects of other underwater noise sources and the possibility that impulsive sources—primarily airguns used in seismic surveys—could cause auditory injury. This led to a series of workshops held in the late 1990s, conducted to address acoustic mitigation requirements for seismic surveys and other underwater noise sources (NMFS 1998, ONR 1998, Nedwell and Turnpenny 1998, HESS 1999, Ellison and Stein 1999). In the years since these early workshops, a variety of thresholds have been proposed for both injury and disturbance. The following sections summarize the recent development of thresholds; however, this field remains an active research topic.

A.3.1. Injury and Hearing Sensitivity Changes

In recognition of shortcomings of the SPL-only based injury criteria, in 2005 NMFS sponsored the Noise Criteria Group to review literature on marine mammal hearing to propose new noise exposure criteria. Some members of this expert group published a landmark paper (Southall et al. 2007) that suggested assessment methods similar to those applied for humans. The resulting recommendations introduced dual acoustic injury criteria for impulsive sounds that included peak pressure level thresholds and SEL_{24h} thresholds, where the subscripted 24h refers to the accumulation period for calculating SEL. The peak pressure level criterion is not frequency weighted whereas SEL_{24h} is frequency weighted according to one of four marine mammal species hearing groups: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively) and Pinnipeds in Water (PINN). These weighting functions are referred to as M-weighting filters (analogous to the A-weighting filter for human; Appendix A.3.3). The SEL_{24h} thresholds were obtained by extrapolating measurements of onset levels of Temporary Threshold Shift (TTS) in belugas by the amount of TTS required to produce Permanent Threshold Shift (PTS) in chinchillas. The Southall et al. (2007) recommendations do not specify an exchange rate, which suggests that the thresholds are the same regardless of the duration of exposure (i.e., it implies a 3 dB exchange rate).

Wood et al. (2012) refined Southall et al.’s (2007) thresholds, suggesting lower injury values for LF and HF cetaceans while retaining the filter shapes. Their revised thresholds were based on TTS-onset levels in harbour porpoises from Lucke et al. (2009), which led to a revised impulsive sound PTS threshold for HF cetaceans of 179 dB re 1 $\mu Pa^2 \cdot s$. Because there were no data available for baleen whales, Wood et al. (2012) based their recommendations for LF cetaceans on results obtained from MF cetacean studies. In particular they referenced Finneran and Schlundt (2010) research, which found mid-frequency cetaceans are more sensitive to non-impulsive sound exposure than Southall et al. (2007) assumed. Wood et al. (2012) thus recommended a more conservative TTS-onset level for LF cetaceans of 192 dB re 1 $\mu Pa^2 \cdot s$.

As of 2017, an optimal approach is not apparent. There is consensus in the research community that an SEL-based method is preferable either separately or in addition to an SPL-based approach to assess the potential for injuries. In August 2016, after substantial public and expert input into three draft versions and based largely on the above-mentioned literature (NOAA 2013, 2015, 2016), NMFS finalised technical guidance for assessing the effect of anthropogenic sound on marine mammal hearing (NMFS 2016). The guidance describes injury criteria with new thresholds and frequency weighting functions for the five hearing groups described by Finneran and Jenkins (2012). The latest revision to this work was published in 2018 (NMFS 2018). Southall et al. (2019) revisited the interim criteria published in 2007; all noise exposure criteria in NMFS (2018) and Southall et al. (2019) are identical (for impulsive and non-impulsive sounds), however the mid-frequency cetaceans from NMFS (2018) are classified as high-frequency cetaceans in Southall et al. (2019), and high-frequency cetaceans from NMFS (2018) are classified as very-high-frequency cetaceans in Southall et al. (2019).

A.3.2. Behavioural response

Numerous studies on marine mammal behavioural responses to sound exposure have not resulted in consensus in the scientific community regarding the appropriate metric for assessing behavioural reactions. However, it is recognised that the context in which the sound is received affects the nature and extent of responses to a stimulus (Southall et al. 2007, Ellison and Frankel 2012, Southall et al. 2016).

NMFS currently uses step function (all-or-none) threshold of 120 dB re 1 µPa SPL (unweighted) for non-impulsive sounds to assess and regulate noise-induced behavioural effects to marine mammals (NOAA 2019). The 120 dB re 1 µPa threshold is associated with non-impulsive sources and was derived based on studies examining behavioural responses to drilling and dredging, referring to Malme et al. (1983), Malme et al. (1984), and Malme et al. (1986), which were considered in Southall et al. (2007). Malme et al. (1986) found that playback of drillship noise did not produce clear evidence of disturbance or avoidance for levels below 110 dB re 1 µPa (SPL), possible avoidance occurred for exposure levels approaching 119 dB re 1 µPa. Malme et al. (1984) determined that measurable reactions usually consisted of rather subtle short-term changes in speed and/or heading of the whale(s) under observation. It has been shown that both received level and proximity of the sound source is a contributing factor in eliciting behavioural reactions in humpback whales (Dunlop et al. 2017, Dunlop et al. 2018).

A.3.3. Marine Mammal Frequency Weighting

The potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal’s sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The overall shape of the auditory weighting functions is similar to human A-weighting functions, which follows the sensitivity of the human ear at low sound levels. The new frequency-weighting function is expressed as:

$$G(f) = K + 10\log_{10}\left(\frac{\left(\frac{f}{f_{lo}}\right)^{2a}}{\left(1+\left(\frac{f}{f_{lo}}\right)^{2}\right)^{a}\left(1+\left(\frac{f}{f_{hi}}\right)^{2}\right)^{b}}\right) \tag{A-11}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid-, and high-frequency cetaceans, phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA’s technical guidance that assesses noise impacts on marine mammals (NMFS 2016, NMFS 2018). A further update to these weighting functions is presented in Southall (2019), whereby mid- and high- frequency cetaceans are now known as high- and very-high-frequency cetaceans. Table A-1 lists the frequency-weighting parameters for each hearing group; Figure A-3 shows the resulting frequency-weighting curves.

Table A-1. Parameters for the auditory weighting functions used in this project as recommended by NMFS (2018) and Finneran et al. (2017).

Hearing group	a	b	f_{lo} (Hz)	f_{hi} (Hz)	K (dB)
LF cetaceans (baleen whales)	1.0	2	200	19,000	0.13
MF cetaceans (dolphins, plus toothed, beaked, and bottlenose whales)	1.6	2	8,800	110,000	1.20
HF cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	1.8	2	12,000	140,000	1.36
Sea turtles	1.4	2	77	440	2.35

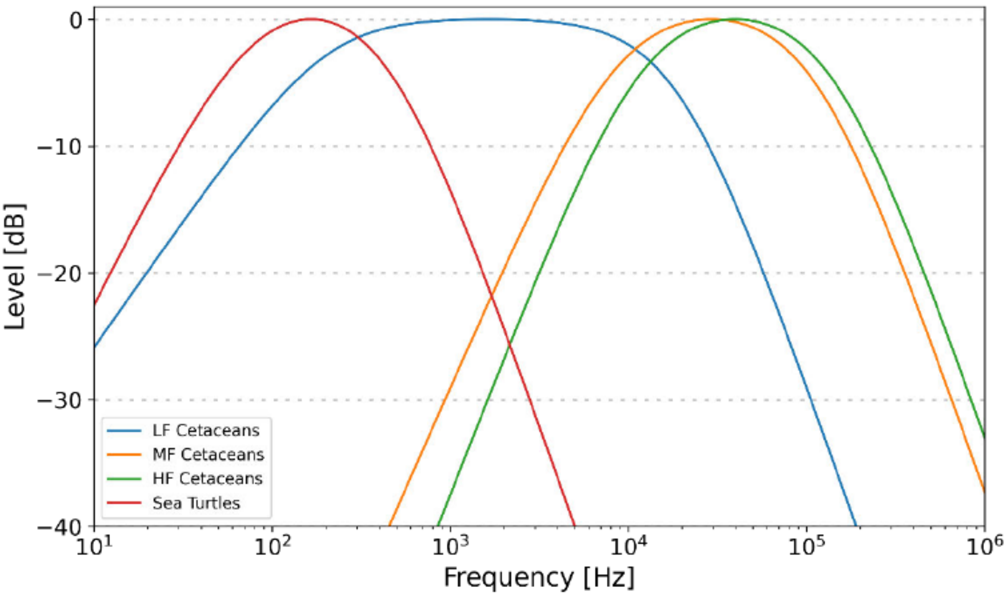

Figure A-3. Auditory weighting functions for functional marine mammal hearing groups as recommended by NMFS (2018) and Finneran et al. (2017)

Appendix B. Sound Source Propagation

B.1. Marine Operations Noise Model

Underwater sound propagation (i.e., transmission loss) at frequencies of 10 Hz to 1.6 kHz was predicted with JASCO's Marine Operations Noise Model (MONM). MONM computes SEL over 1 s for non-impulsive sources, at a specified source depth. Sound propagation at frequencies of 2 kHz and greater was computed via the BELLHOP Gaussian beam acoustic ray-trace model (Porter and Liu 1994).

MONM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the US Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for a solid seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM accounts for the additional reflection loss at the seabed, which results from partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates the following site-specific environmental properties: a bathymetric grid of the modelled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor. Additionally, BELLHOP accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water (Fisher and Simmons 1977). This type of sound attenuation is important for frequencies higher than 5 kHz and cannot be neglected without noticeably affecting the model results.

MONM computes acoustic fields in three dimensions by modelling transmission loss within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as *N*×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding $N = 360°/\Delta\theta$ number of planes (Figure B-1).

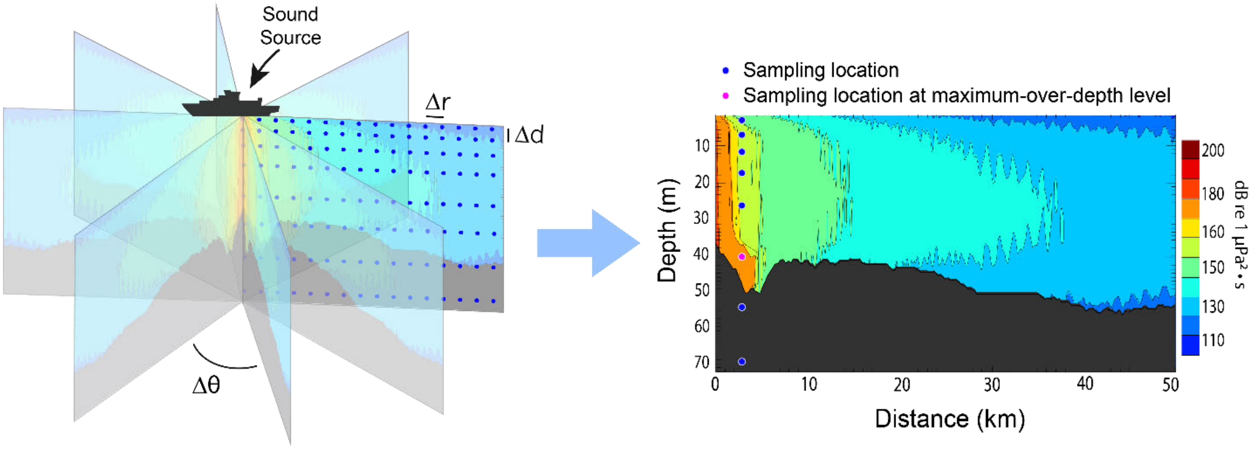

Figure B-1. The *N*×2-D and maximum-over-depth modelling approach used by MONM

MONM treats frequency dependence by computing acoustic transmission loss at the centre frequencies of decidecade bands. Sufficiently many decidecade frequency-bands, starting at 10 Hz, are modelled to include most of the acoustic energy emitted by the source. At each centre frequency, the transmission loss is modelled within each of the N vertical planes as a function of depth and range from the source. The decidecade received per-pulse SEL are computed by subtracting the band propagation loss values from the directional source level in that frequency band. Composite broadband received per-pulse SEL are then computed by summing the received decidecade levels.

The received per-pulse SEL sound field within each vertical radial plane is sampled at various ranges from the source, generally with a fixed radial step size (Δr in Figure B-1). At each sampling range along the surface, the sound field is sampled at various depths (Δd in Figure B-1), with the step size between samples increasing with depth below the surface. The step sizes are chosen to provide increased coverage near the depth of the source and at depths of interest for the sound speed profile. For areas with deep water, sampling is not performed at depths beyond those reachable by marine mammals. The received per-pulse SEL at a surface sampling location is taken as the maximum value that occurs over all samples within the water column, i.e., the maximum-over-depth received per-pulse SEL. These maximum-over-depth per-pulse SEL are presented as colour contours around the source.

MONM’s predictions have been validated against experimental data from several underwater acoustic measurement programs conducted by JASCO (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010, Racca et al. 2012a, Racca et al. 2012b, Martin et al. 2015).

Appendix C. Additional Methods and Parameters

C.1. Estimating Ranges to Threshold Levels

Sound level contours were calculated based on the underwater sound fields predicted by the propagation models, sampled by taking the maximum value over all modelled depths above the seafloor for each location in the modelled region. The predicted ranges to specific levels were computed from these contours. Two ranges relative to the source are reported for each sound level: R_{max}, the maximum range to the given sound level over all azimuths, and $R_{95\%}$, the range to the given sound level after the 5% farthest points were excluded (see examples in Figure C.1).

The $R_{95\%}$ is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in Figure C.1a. In cases such as this, where relatively few points are excluded in any given direction, R_{max} can misrepresent the area of the region exposed to such effects, and $R_{95\%}$ is considered more representative. In contrast, in strongly radially asymmetric cases such as shown in Figure C.1b, $R_{95\%}$ neglects to account for substantial protrusions in the footprint. In such cases, R_{max} might better represent the region of effect in specific directions. Cases such as this are usually associated with bathymetric features that affect propagation. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the non-uniformity of the acoustic environment.

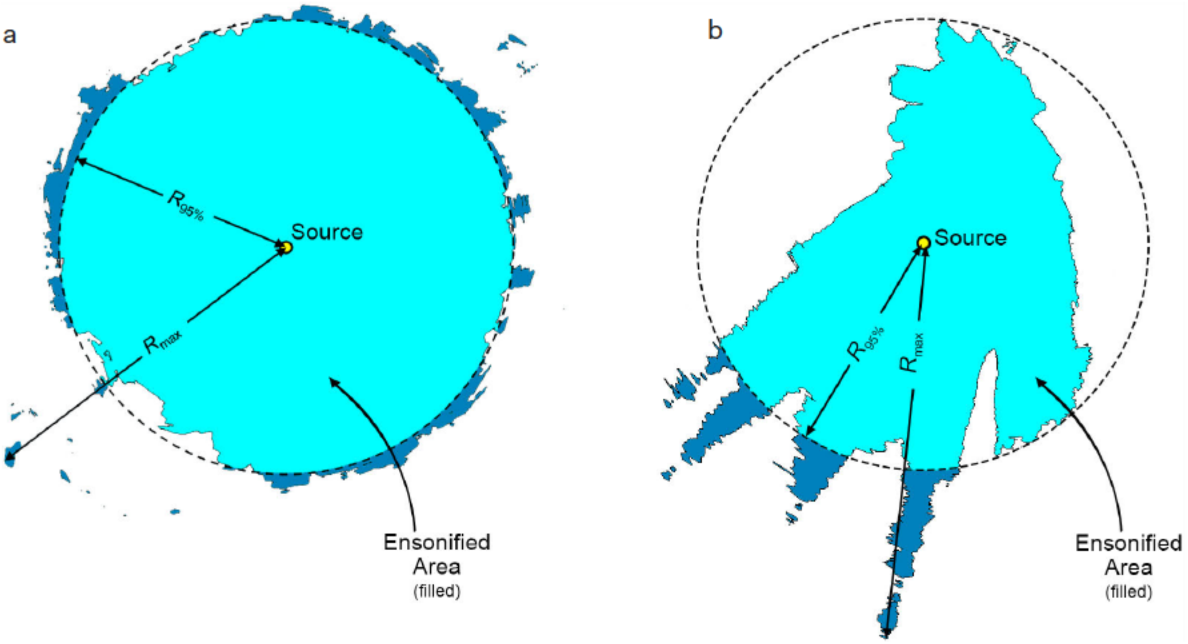

Figure C.1. R_{max} and $R_{95\%}$ ranges shown for two contrasting scenarios. Cyan indicates the ensonified areas bounded by $R_{95\%}$, whilst dark blue indicates the ensonified areas beyond $R_{95\%}$ that determine R_{max}.

C.2. Environmental Parameters

The parameters used are the same as applied in McPherson et al. (2019).

C.2.1. Bathymetry

Water depths (Mean Sea Level) at close- and mid-range from the Torosa field were provided by the BJV. Within ~5–7 km from the pile, the data has a grid resolution of 2 × 2 m, while data at the passage between Scott Reef South and Scott Reef Central has a grid resolution of 1 × 1 m. Bathymetry data with grid resolution of 10 × 10 m was provided as far as 33 km northeast of the pile, and as far as 85 km southwest of the pile. Modelling was conducted along 80 km long radials emanating from the pile in all directions. For this reason, the high-resolution data was complemented using the Australian Bathymetry and Topography Grid, a 9 arc-second grid rendered for Australian waters (Whiteway 2009). The data were adjusted for an increase of 1.7 m in depth (Bureau of Meterology 2019), so the modelling results correspond to the most conservative propagation conditions at maximum tide at Scott Reef. Bathymetry data were re-gridded onto a Map Grid of Australia (MGA) coordinate projection (Zone 51) with a regular grid spacing of 50 × 50 m.

C.2.2. Sound speed profile

The sound speed profile in the area was derived from temperature and salinity profiles from the U.S. Naval Oceanographic Office's *Generalized Digital Environmental Model V 3.0* (GDEM; Teague et al. 1990, Carnes 2009). GDEM provides an ocean climatology of temperature and salinity for the world's oceans on a latitude-longitude grid with 0.25° resolution, with a temporal resolution of one month, based on global historical observations from the U.S. Navy's Master Oceanographic Observational Data Set (MOODS). The climatology profiles include 78 fixed depth points to a maximum depth of 6800 m (where the ocean is that deep). The GDEM temperature-salinity profiles were converted to sound speed profiles according to Coppens (1981).

Mean monthly sound speed profiles were derived from the GDEM profiles at distances less than 76 km around the modelled site. The June sound speed profile is expected to be most favourable to longer-range sound propagation across the entire year. As such, June was selected for sound propagation modelling to ensure precautionary estimates of ranges to received sound level thresholds. Figure C-2 shows the resulting profile, which was used as input to the sound propagation modelling.

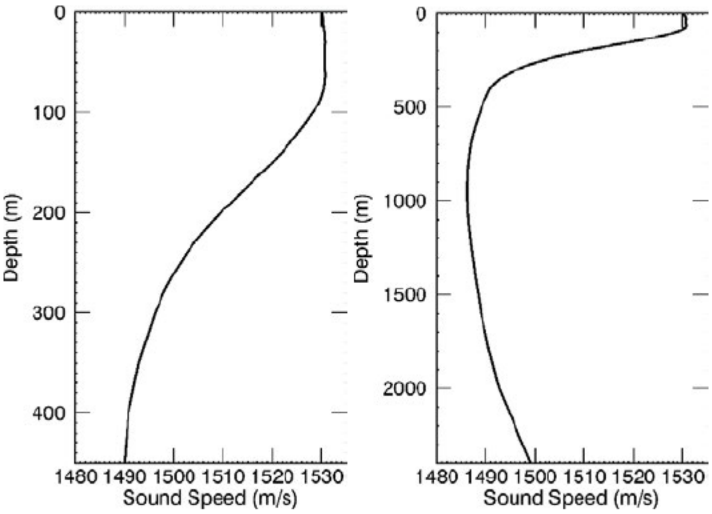

Figure C-2. The modelling sound speed profile corresponding to June: (left) top 450 m and (right) full profile. Profiles are calculated from temperature and salinity profiles from *Generalized Digital Environmental Model* V 3.0 (GDEM; Teague et al. 1990, Carnes 2009).

C.2.3. Geoacoustics

In previous acoustic studies in the area (Duncan 2014, McPherson et al. 2019), the modelling area was divided into three seabed types, with a silt seabed typical of the continental slope considered for most of the modelling area, and coarser gravel and limestone in the areas in and around the reefs. Due to the type of propagation modelling used in this study, however, the silt seabed was used for the entire modelling area. This is detailed in Table C-1.

Table C-1. Continental slope geoacoustic profile. Within each depth range, each parameter varies linearly within the stated range. The compressional wave is the primary wave, and the shear wave is the secondary wave.

Depth below seafloor (m)	Material	Density (g/cm^3)	Compressional wave		Shear wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0–50	Silt	1.70–1.75	1566–1627	1.0	210	1.5
50–100		1.75–1.80	1627–1686			
100–150		1.80–1.85	1686–1742			
150–200		1.85–1.90	1742–1795			
>200		1.90	1795			

Appendix C - Woodside Browse to NWS Vessel Animat Modelling (Cusano *et al* 2022)

Woodside Browse to NWS Vessel Noise

Animat Modelling

JASCO Applied Sciences (Australia) Pty Ltd

11 February 2022

Submitted to:

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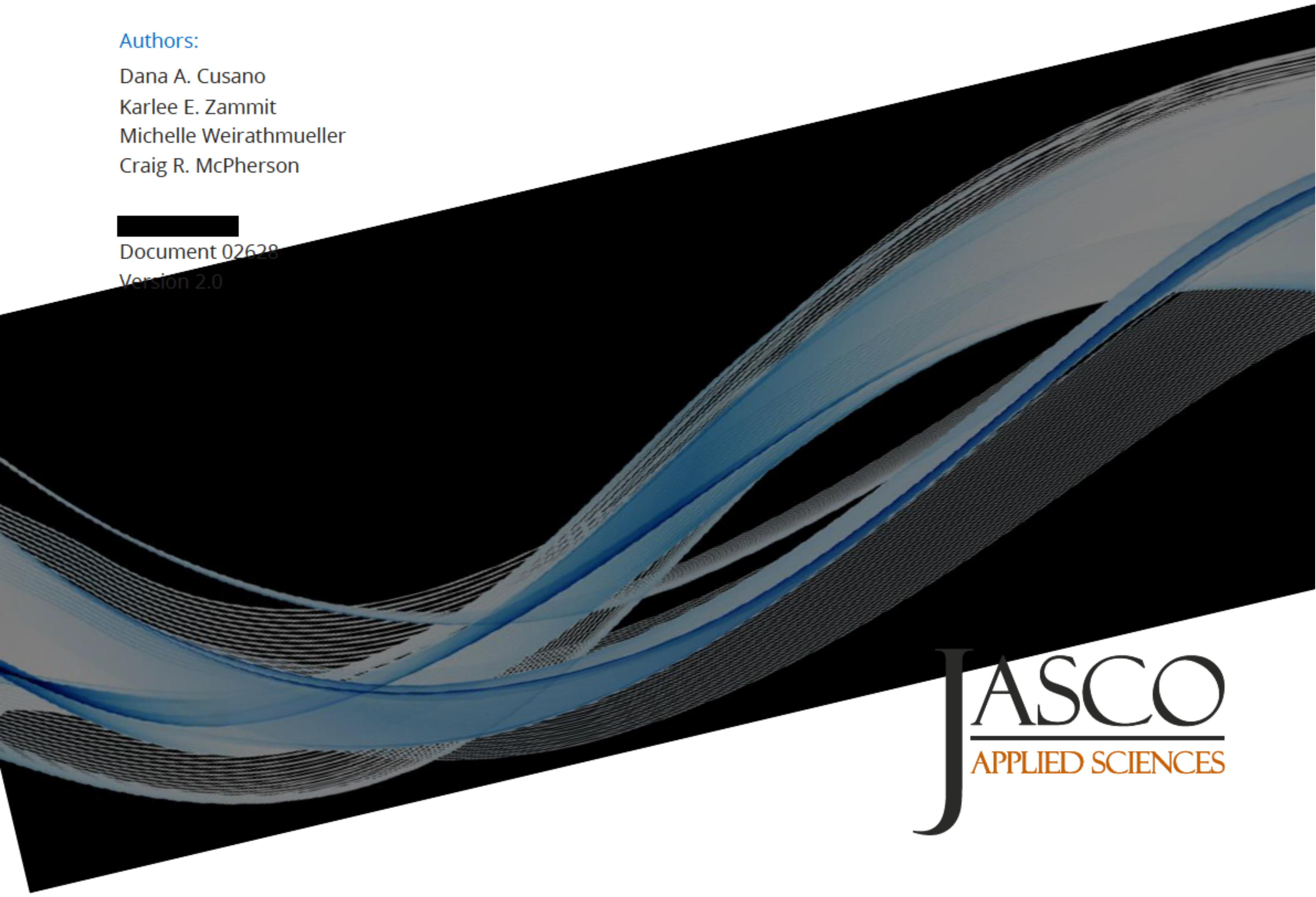

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Contents

Figures

Tables

Executive Summary

JASCO Applied Sciences performed an acoustic exposure analysis study of pygmy blue whales near a migratory and feeding Biologically Important Area (BIA) where they intersected the planned development and installation area for the Brecknock, Calliance, and Torosa fields (collectively known as the Browse resources) proposed by the Browse Joint Venture (BJV). Previously, acoustic modelling was conducted for Mobile Offshore Drilling Unit (MODU) and Floating Production Storage and Offloading (FPSO) operations to determine ranges to acoustic exposure thresholds representing the best available science for potential injury, impairment and behavioural reactions of marine fauna including marine mammals, turtles, and fish (Green et al. 2021).

The aim of the present study was to employ animal movement (animat) modelling simulations in conjunction with these previously computed three-dimensional sound fields to predict the range at which pygmy blue whales are expected to be exposed above threshold criteria for permanent threshold shift (PTS), temporary threshold shift (TTS) and behavioural response. To achieve this, the JASCO Animal Simulation Model Including Noise Exposure (JASMINE) was used to integrate the sound fields with species-typical behaviour, with the pygmy blue whales represented by animats. JASMINE results provide a probabilistic estimate of sound exposure, which can be compared to acoustic thresholds to determine ranges.

Animat modelling focussed on migrating pygmy blue whales (*Balaenoptera musculus brevicauda*) in the migratory BIA and feeding pygmy blue whales in the foraging BIA. The behaviour of migrating pygmy blue whales was modelled with a directional bias of 230 degrees to represent the south-bound migration and 30 degrees to represent the north-bound migration, while feeding pygmy blue whales were presumed to remain in the feeding BIA to represent the behaviour of whales on a feeding stopover during their migration.

To generate statistically reliable probability density functions, and thus range estimates, model simulations were run with animat densities of 3 animats/km^2. The modelling results are not related to real-world density estimates for pygmy blue whales as the number of animals potentially exposed is not calculated.

Four exposure modelling scenarios were simulated to correspond with a selected subset of the scenarios from the acoustic modelling, with each simulation run for a period of 24 hours to match the acoustic modelling approach. Using the distribution of ranges of animats predicted to be exposed to sound levels above threshold, the 95th percentile exposure range ($ER_{95\%}$) was computed. Within the $ER_{95\%}$, there is generally some proportion of animats that do not exceed threshold criteria. This reason is different for different thresholds, however could include animats not being exposed long enough to exceed accumulated SEL thresholds, or swimming at depths which are not ensonified to a level which could lead to exposure. Therefore, the probability that an animat within that distance was exposed above threshold within the $ER_{95\%}$ was also computed (P_{exp}).

Noise effect metrics included sound exposure levels (SEL), and sound pressure level (SPL), The results of the animat analysis predicted that the $ER_{95\%}$ of migrating pygmy blue whales potentially exposed to sound levels above the U.S National Marine Fisheries Service (NMFS) (2018) PTS and TTS criteria were up to 0.01 km (P_{exp} 3-33%) and 0.05 km (P_{exp} 27-78%) respectively, from all scenarios using SEL_{24h} metrics (Table 1). The maximum $ER_{95\%}$ for exposures above the U.S. National Oceanic and Atmospheric Administration (NOAA) (2019) behavioural threshold from all scenarios was 2.78 km, with a P_{exp} of 81%.

The estimated exposure ranges for PTS and TTS for all scenarios were shorter than comparable ranges to threshold reported in Green et al. (2021). This was expected because previous modelling efforts did not incorporate both moving sources and moving receivers, but rather assumed that, as per the NMFS (2018) criteria, SEL_{24h} is a cumulative metric that reflects the dosimetric effect of noise

levels within 24 hours considering that an animal is consistently exposed to such noise levels at a fixed position.

The estimated exposure ranges for the behavioural SPL criteria were comparable to the acoustic ranges (Green et al. 2021), although $ER_{95\%}$ and (P_{exp}) for foraging animats was consistently higher than for migrating animats. This difference arises from the way in which the foraging and migrating animats sample the water column. Foraging animats dive deeper and spend more time at depth than migrating animats. Because of this, they are exposed to sound levels exceeding the behavioural threshold at longer ranges. There was no quantifiable difference between the northbound and southbound migratory simulations for TTS, PTS, or behavioural thresholds.

One aggregate scenario was run to simulate the potential effects with all sources running simultaneously. As was observed in the acoustic modelling analysis, exposure ranges for the aggregate scenario were not significantly different than during individual operations (Green et al. 2021).

Table 1. Summary of animat simulation results. The 95th percentile exposures ranges ($ER_{95\%}$) in km and probability of animats being exposed above threshold within the $ER_{95\%}$ (P_{exp} (%)) are provided.

Threshold		Scenario 4(a) MODU under DP at TRD		Scenario 7 Torosa FPSO		Scenario 8 Torosa FPSO Offtake		Scenario 9 Aggregate Scenario	
Description	Threshold level (dB)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)
South-bound migrating pygmy blue whales									
TTS (SEL_{24h})	179[a]	0.02	27	0	0	0.05	46	0.05	34
PTS (SEL_{24h})	199[a]	0	0	0	0	0	0	0	0
Behavioural response (SPL)	120[b]	2.22	76	0.37	73	1.38	88	2.22	82
North-bound migrating pygmy blue whales									
TTS (SEL_{24h})	179[a]	0.03	39	0	0	0.04	78	0.04	40
PTS (SEL_{24h})	199[a]	0	0	0	0	0.01	25	0.01	3
Behavioural response (SPL)	120[b]	2.28	83	0.37	71	1.49	81	2.28	90
Foraging pygmy blue whales									
TTS (SEL_{24h})	179[a]	0.03	53	0	0	0.01	50	0.03	41
PTS (SEL_{24h})	199[a]	0	0	0	0	0.01	33	0.01	12
Behavioural response (SPL)	120[b]	2.68	92	0.52	100	1.91	92	2.78	81

[a] LF-weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa^2·s)

[b] SPL (L_p; dB re 1 µPa)

1. Introduction

JASCO Applied Sciences (JASCO), performed an acoustic exposure analysis study for pygmy blue whales (*Balaenoptera musculus brevicauda*) in association with the planned Browse to North West shelf (NWS) Project development of the Brecknock, Calliance, and Torosa fields (collectively known as the Browse resources) by the Browse Joint Venture (BJV). This development will involve drilling wells and installing a subsea production system that will supply two 1100 million standard cubic feet per day (annual daily export average) Floating Production Storage and Offloading (FPSO) facilities. Gas will be transported from the FPSO facilities to the existing NWS Project infrastructure via an approximately 900 km long trunkline. Each FPSO will have a turret mooring system that will be stabilised using mooring lines secured to the seabed by piles.

The acoustic modelling results were used in conjunction with animal movement modelling simulations to predict the distance at which pygmy blue whales are expected to be exposed above threshold criteria for injury (temporary threshold shift (TTS) and permanent threshold shift (PTS)), and behavioural response. Sound exposure distribution estimates are determined by moving large numbers of simulated animals (animats) through a modelled time-evolving sound field, computed using specialised sound source and sound propagation models. This approach provides the most realistic prediction of the maximum expected root-mean-square sound pressure level (SPL, L_p) and the temporal accumulation of sound exposure level (SEL, L_E) for comparison against the relevant thresholds.

The present animat modelling study considers the following scenarios:

- The operations of a Mobile Offshore Drilling Unit (MODU) during drilling operations using four thrusters at the TRD drill centre.
- FPSO operational noise for the Torosa FPSO without heading control.
- Torosa FPSO operational noise during offtake, including the FPSO without heading control, an Offshore Support Vessel (OSV) near the FPSO and a noiseless condensate tanker.
- Aggregate scenarios that include MODU operations at TRD and the Torosa FPSO during offtake operations.

Green et al. (2021) conducted a detailed sound modelling study, and the resulting sound fields were used to predict animat sound exposures. The geographic coordinates for the modelled sites that were used in the current analysis are provided in Table 2 and an overview of the acoustic modelling area is shown in Figure 1.

Table 2. Location details for the modelled sites from Green et al. (2021). Sites and sources used in animat exposure modelling are highlighted in bold.

Site	Source	Latitude (S)	Longitude (E)	MGA (GDA94), Zone 51		Water depth (m)
				X (m)	Y (m)	
TRA Well	MODU (centre)	13° 58′ 12.50″	121° 58′ 37.70″	389521	8455338	425
	OSV (centre)	13° 58′ 12.49″	121° 58′ 35.70″	389461	8455338	425
TRD Well	**MODU (centre)**	**14° 00′ 26.64″**	**121° 57′ 23.58″**	**387315**	**8451207**	**392**
	OSV (centre)	14° 00′ 26.63″	121° 57′ 21.58″	387255	8451207	392
Torosa FPSO	**FPSO (centre)**	**13° 58′ 15.06″**	**122° 01′ 28.53″**	**394647**	**8455281**	**463**
	OSV (centre)	**13° 58′ 14.94″**	**122° 00′ 59.03″**	**393762**	**8455281**	**460**

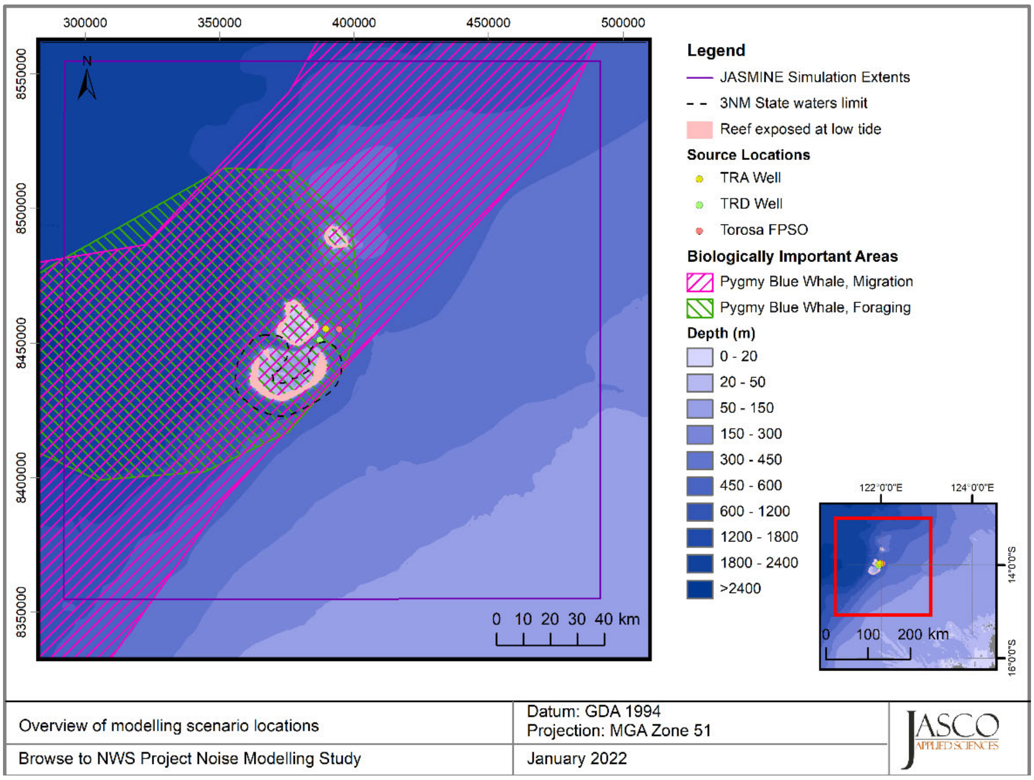

Figure 1. Overview of the modelled area and local features.

1.1. Exposure Modelling Scenario Details

For the planned Browse to NWS Project development, source and propagation modelling were conducted (Green et al. 2021) to generate sound fields which were used in conjunction with animal movement modelling. The acoustic modelled sources were as follows:

- *An FPSO facility* that is 370 m long and 67 m wide. This was modelled under:
    - Typical operations, with no heading control and no offtake, only operating processing and associated equipment,
    - Heading control (thrusters operating), representative of typical operational conditions,
    - Heading control (thrusters operating) with optimised thrusters, representative of typical operational conditions, and
    - Offtake, during which the FPSO is only operating processing and associated equipment.
- *A representative MODU* that is 100 × 80 m under DP, representative of typical operational noise during 1-year (non-cyclonic) return interval metocean conditions. This was modelled using:
    - Four thruster sources operating at 40% capacity, and
    - A central machinery source, representative of a typical drilling operation.
- *A representative OSV*, a DP vessel 92.95 m long (vessel design based on the Marin Teknikk MT6016 hull) under DP, representative of typical operational noise during maximum safe operating conditions and resupply operations. This was modelled using five thruster sources operating at a defined capacity, based on the specification of the *Fugro Etive*, as follows:
    - Two Rolls-Royce AZP100 thrusters,
    - Two Rolls Royce TT 2200 DPN thrusters, and
    - One Rolls-Royce AZP1001 thruster.

These vessels were modelled in varying configurations at the three different locations shown in Figure 1. Animat exposure modelling scenarios were simulated for Scenarios 4(a), 7, 8, and 9. The acoustic scenarios and animat scenarios are summarised in Table 3.

Table 3. Modelled scenarios from Green et al. (2021). Scenarios used in animat exposure modelling are highlighted in bold.

Scenario	Description	Sources	Length of operation	Animat Modelling
TRA well				
1(a)	MODU drilling	MODU drilling and thrusters (4 × 40%)	24 h	Not Considered
1(b)	MODU drilling (moored)	MODU drilling, no thrusters	24 h	Not Considered
2	Offshore Support Vessel	Support vessel (DP)	6 and 12 h	Not Considered
3	MODU resupply	MODU drilling and thrusters (4 × 40%) Support vessel (DP)	24 h 6 and 12 h	Not Considered
TRD well				
4(a)	**MODU drilling**	**MODU drilling and thrusters (4 × 40%)**	**24 h**	**Considered**
4(b)	MODU drilling (moored)	MODU drilling, no thrusters	24 h	Not Considered
5	Offshore Support Vessel	Support vessel (DP)	6 and 12 h	Not Considered
6	MODU resupply	MODU drilling and thrusters (4 × 40%) Support vessel (DP)	24 hr 6 and 12 h	Not Considered
Torosa				
7	**FPSO**	**Topsides machinery**	**24 h**	**Considered**
7(a)	FPSO using heading control	FPSO thrusters and topsides machinery	24 h	Not Considered
7(b)	FPSO using optimised heading control	Optimised FPSO thrusters and topsides machinery	24 h	Not Considered
8	**FPSO offtake**	**FPSO with topsides machinery** **Silent Tanker** **Support vessel (DP)**	**24 h**	**Considered**
TRD well and Torosa				
9	**MODU drilling at TRD, Torosa FPSO Offtake**	**MODU drilling and thrusters (4 × 40%)** **Support vessel (DP)** **FPSO with topsides machinery** **Silent Tanker**	**24 h**	**Considered**

The migratory and foraging BIAs overlap with the project area. Simulated animats were seeded only within the BIAs to represent the spatial distribution of this species. Animat exposure modelling simulation extents and animat seeding areas (BIAs) are shown in Figure 1.

2. Noise Effect Criteria

The noise effect criteria which were considered for pygmy blue whales in this assessment are the same as those applied and described in the acoustic modelling study (Green et al. 2021). The criteria relate to assessing permanent threshold shift (PTS), temporary threshold shift (TTS) and behavioural response in pygmy blue whales and are summarised in Table 4.

Table 4. Criteria for effects of non-impulsive noise exposure, including vessel noise on marine mammals: SPL and Weighted SEL$_{24h}$ thresholds.

Hearing group	NOAA (2019)	NMFS (2018)	
	Behaviour	PTS onset thresholds (received level)	TTS onset thresholds (received level)
	SPL (L_p; dB re 1 µPa)	Weighted SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa^{2}s)	Weighted SEL$_{24h}$ ($L_{E,24h}$; dB re 1 µPa^{2}s)
LF cetaceans	120	199	179
MF cetaceans		198	178
HF cetaceans		173	153

L_p denotes sound pressure level period and has a reference value of 1 µPa.
L_E denotes cumulative sound exposure over a 24 h period and has a reference value of 1 µPa^{2}s.

3. Methods

3.1. Animal Movement and Exposure Modelling

The JASCO Animal Simulation Model Including Noise Exposure (JASMINE) was used to predict the exposure of animats to sound arising from the vessel and equipment operations. JASMINE integrates the predicted sound field with biologically meaningful movement rules for each marine mammal species (pygmy blue whales for the current analysis) that results in an exposure history for each animat in the model. In JASMINE, the sound received by the animats is determined by the proposed operations. As illustrated in Figure 2, animats are programmed to behave like the marine animals that may be present in an area. The parameters used for forecasting realistic behaviours (e.g., diving and foraging depth, swim speed, surface times) are determined and interpreted from marine mammal studies (e.g., tagging studies) where available, or reasonably extrapolated from related or comparable species. For cumulative metrics, an individual animat's sound exposure levels are summed over a 24 h duration to determine its total received energy, and then compared to the relevant threshold criteria. For single-exposure metrics metrics, the maximum exposure is evaluated against threshold criteria for each 24 h period. For additional information on JASMINE, see Appendix A.

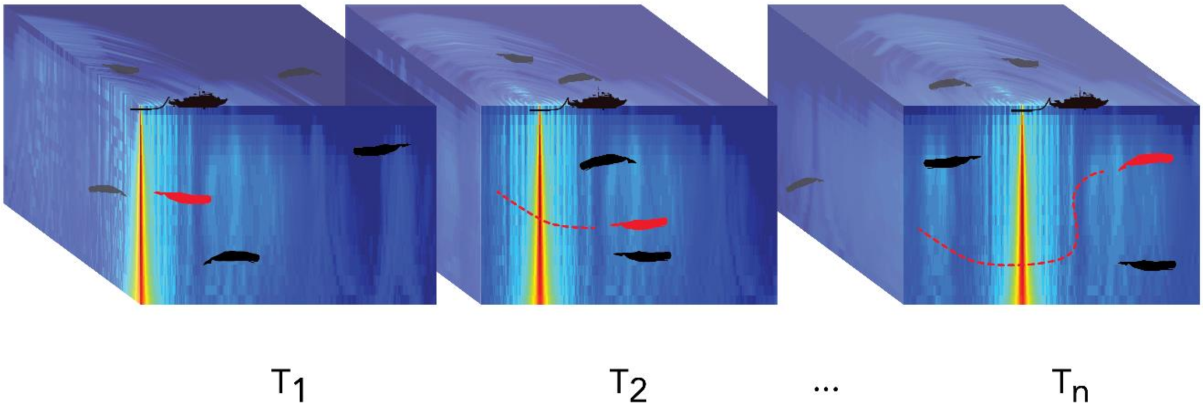

Figure 2. Cartoon of animats in a moving sound field. Example animat (red) shown moving with each time step (T_n). The acoustic exposure of each animat is determined by where it is in the sound field, and its exposure history is accumulated as the simulation steps through time.

The simulation was run for a representative period of 24 hours to coincide with the acoustic modelling effort. The modelling results presented in this report are not related to real-world density estimates for pygmy blue whales within the migration BIA and the number of animals potentially exposed was not calculated. To evaluate PTS, TTS, and behavioural response, exposure results were obtained using detailed behavioural information for migrating and feeding pygmy blue whales (described in Section 3.1.2). The spatial distribution of animats was restricted to the BIAs for all assessed scenarios, with the migration behavioural profile limited to the migration BIA and the feeding behavioural profile limited to the foraging BIA.

Model parameters related to spatial and temporal sampling were selected to appropriately capture both the swimming behaviours and the predicted sound fields. Within the context of the project-specific simulation parameters, including source characteristics, swimming behaviours, and bathymetry, a seeding density of 3 animats per km^2 was determined to provide sufficient sampling of the model space and to generate statistically reliable exposure range estimates (see Appendix A.1.3 for additional details). This resulted in 97 346 south-bound migrating animats, 86 769 north-bound migrating animats and 55 649 foraging animats across all modelling scenarios. Additionally, each animat was programmed to sample the model space every 5 seconds. For example, an animat swimming at 1 m/s would sample the sound field every 5 meters along its track.

3.1.1. Exposure-based Radial Distance Estimation

The results from the animal movement and exposure modelling provided a way to estimate radial distances to effect thresholds. The distance to the closest point of approach (CPA) for each of the animats was recorded. The $ER_{95\%}$ (95% Exposure Range) is the horizontal distance that includes 95% of the animat CPAs that exceeded a given effect threshold (Figure 3). Within the $ER_{95\%}$, there is generally some proportion of animats that do not exceed threshold criteria. The probability that an animat is exposed above threshold within the $ER_{95\%}$ is provided in the results tables.

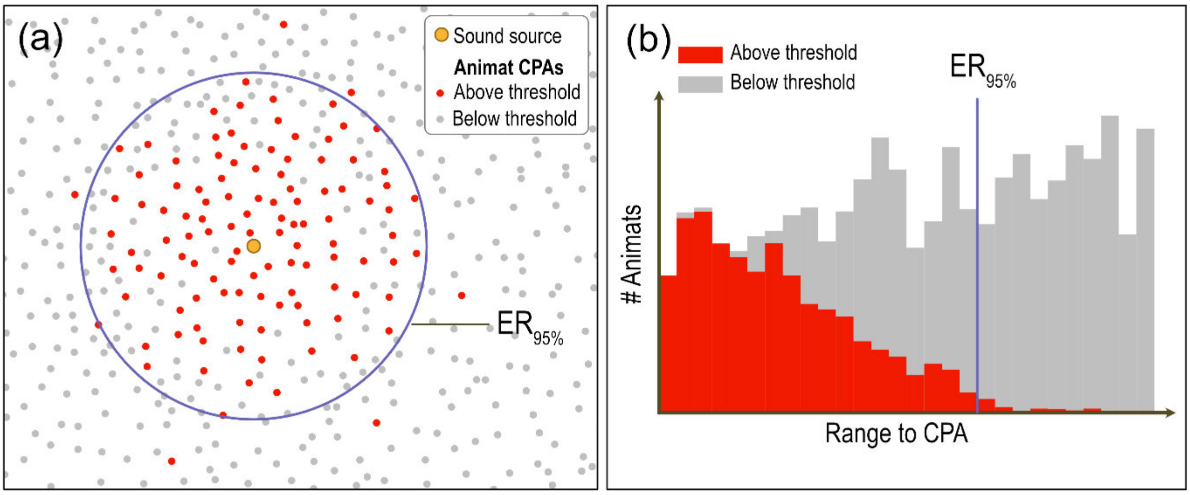

Figure 3. Example distribution of animat closest points of approach (CPAs). Panel (a) shows the horizontal distribution of animats near a sound source. Panel (b) shows the distribution of distances to animat CPAs. The 95% exposure range ($ER_{95\%}$) is indicated in both panels.

3.1.2. Pygmy Blue Whale Behaviour

The Browse to NWS Project development is within the migration and foraging BIAs for pygmy blue whales, therefore both behaviours were considered. Additionally, the south-bound and north-bound migrations were both modelled. Detailed information on pygmy blue whales was derived from a range of sources that used multi-sensor tags to record fine-scale dive and movement behaviour (Owen et al. 2016, AIMS unpublished data 2021), as well as satellite tags to record travel speed (Thums and Ferreira 2021).

Multi-sensor tags typically record the depth of an animal along with various movement parameters such as swim speed and their body's orientation. Owen et al. (2016) equipped a sub-adult pygmy blue whale with a multi-sensor tag off Western Australia. They identified dives for the tagged animal as migratory, feeding, or exploratory (i.e., no lunges recorded which would indicate feeding). Pygmy blue whales in the simulation area are presumed to be either migrating or feeding depending on the BIA in which they are located, and so the two behavioural profiles were modelled separately. Exploratory dives were considered to be part of migratory behaviour, and so the two dive types were modelled together such that the animats were migrating 95% of the time and engaged in exploratory dives 5% of the time (Owen et al. 2016). For the feeding behavioural profile, animats were assumed to be engaged in feeding behaviour 100% of the time. Using data from Owen et al. (2016), the approximate length of a bout of exploratory dives could be determined, as well as the average (± SD) depth of this dive type.

The speed of travel and turn angle (i.e., the change in heading between satellite locations) for all dive behaviours were calculated from data presented in Thums and Ferreira (2021), who analysed data from satellite tags deployed on pygmy blue whales in the Northwest Marine Region. All remaining parameters were calculated from two multi-sensor tags deployed on pygmy blue whales off Western Australia (AIMS unpublished data 2021).

The behaviour of migrating pygmy blue whales was modelled to reflect animats transiting through the modelling area on a 230° track for the southward migration, and a 30° track for the northward migration. This represents the animals migrating along the west coast of Australia from their breeding grounds in Indonesia (Double et al. 2014, Thums and Ferreira 2021).

4. Results

A summary of radial distances to exposure thresholds for pygmy blue whales, along with probability of exposure for each modelled scenario (Table 3) are included in Table 5-Table 7. Results include $ER_{95\%}$ exposure ranges calculated for the 120 dB behavioural response threshold and SEL thresholds for both TTS and PTS, and the probability of an animat being exposed above the threshold within the $ER_{95\%}$.

Table 5. Summary of animat simulation results for south-bound migrating pygmy blue whales. The 95th percentile exposures ranges ($ER_{95\%}$) in km and probability of animats being exposed above threshold within the $ER_{95\%}$ (P_{exp} (%)) are provided.

Threshold		Scenario 4(a) MODU under DP at TRD		Scenario 7 Torosa FPSO		Scenario 8 Torosa FPSO Offtake		Scenario 9 Aggregate Scenario	
Description	Threshold level (dB)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)
TTS (SEL_{24h})	179[a]	0.02	27	0	0	0.05	46	0.05	34
PTS (SEL_{24h})	199[a]	0	0	0	0	0	0	0	0
Behavioural response (SPL)	120[b]	2.22	76	0.37	73	1.38	88	2.22	82

[a] LF-weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)

[b] SPL (L_p; dB re 1 µPa)

Table 6. Summary of animat simulation results for north-bound migrating pygmy blue whales. The 95th percentile exposures ranges ($ER_{95\%}$) in km and probability of animats being exposed above threshold within the $ER_{95\%}$ (P_{exp} (%)) are provided.

Threshold		Scenario 4(a) MODU under DP at TRD		Scenario 7 Torosa FPSO		Scenario 8 Torosa FPSO Offtake		Scenario 9 Aggregate Scenario	
Description	Threshold level (dB)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)
TTS (SEL_{24h})	179[a]	0.03	39	0	0	0.04	78	0.04	40
PTS (SEL_{24h})	199[a]	0	0	0	0	0.01	25	0.01	3
Behavioural response (SPL)	120[b]	2.28	83	0.37	71	1.49	81	2.28	90

[a] LF-weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)

[b] SPL (L_p; dB re 1 µPa)

Table 7. Summary of animat simulation results for foraging pygmy blue whales. The 95th percentile exposures ranges ($ER_{95\%}$) in km and probability of animats being exposed above threshold within the $ER_{95\%}$ (P_{exp} (%)) are provided.

Threshold		Scenario 4(a) MODU under DP at TRD		Scenario 7 Torosa FPSO		Scenario 8 Torosa FPSO Offtake		Scenario 9 Aggregate Scenario	
Description	Threshold level (dB)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)	$ER_{95\%}$ (km)	P_{exp} (%)
TTS (SEL_{24h})	179[a]	0.03	53	0	0	0.01	50	0.03	41
PTS (SEL_{24h})	199[a]	0	0	0	0	0.01	33	0.01	12
Behavioural response (SPL)	120[b]	2.68	92	0.52	100	1.91	92	2.78	81

[a] LF-weighted SEL_{24h} ($L_{E,24h}$; dB re 1 µPa²·s)

[b] SPL (L_p; dB re 1 µPa)

Figures 4-6 show histograms of CPA ranges for each animat in the migratory and foraging simulations. The exposure ranges from animal movement modelling are indicated along with both the $R_{95\%}$ and R_{max} from acoustic propagation modelling.

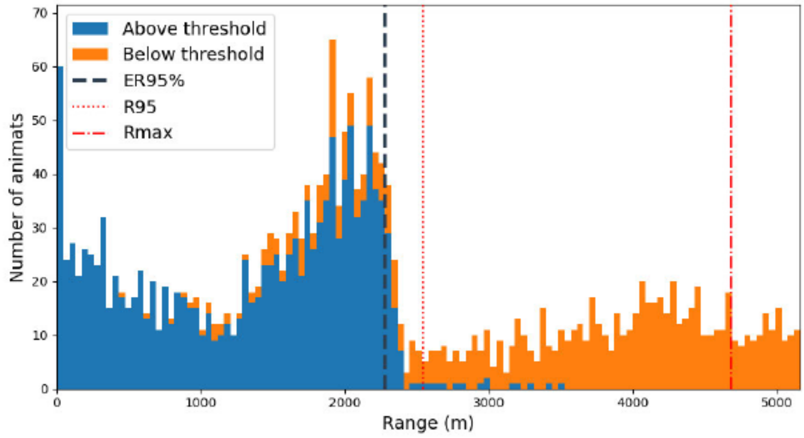

Figure 4. *North-bound migration animats*: CPA range histogram for animats for the MODU under DP at TRD drill centre). Bar colours indicate whether the animats exceeded the SPL behavioural threshold.

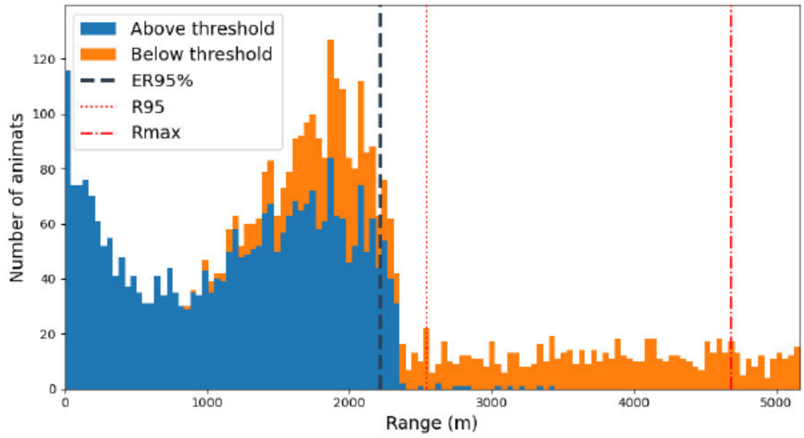

Figure 5. *South-bound migration animats:* CPA range histogram for animats for the MODU under DP at TRD drill centre. Bar colours indicate whether the animats exceeded the SPL behavioural threshold.

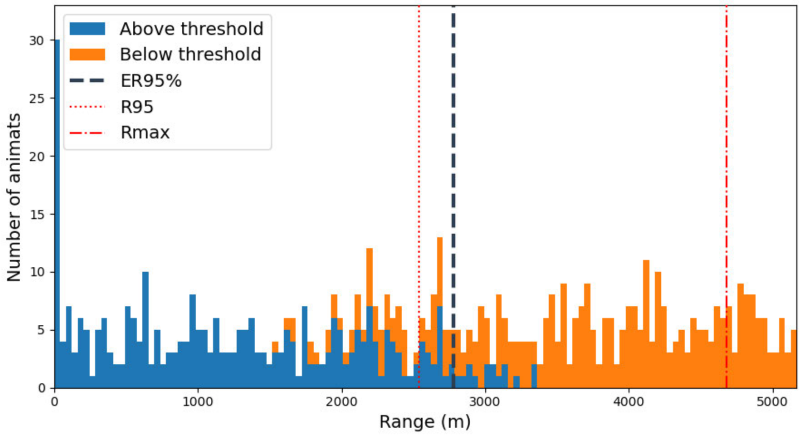

Figure 6. *Foraging animats*: CPA range histogram for animats for the MODU under DP at TRD drill centre.

To provide context and a demonstration of the movements and exposures of animats, during the modelling, 20 random animat tracks were saved from Scenario 9, the aggregate scenario for foraging animats. The animats for which the exposure history is saved are nominated prior to seeding into the simulation, thus their path and exposures are unknown. Of these 20 random animats which had their history saved, only 11 were exposed to the sound field, i.e. came close enough to the source to be exposed. The track for the animat which approached closest to the sound sources (23 km), and thus experienced the highest SPL (95 dB re 1 µPa) and SEL (136 dB re 1 µPa^{2}s) is shown in Figure 7. Figure 8 shows the range to the source as well as the accumulated SEL during the course of the simulation for that animat.

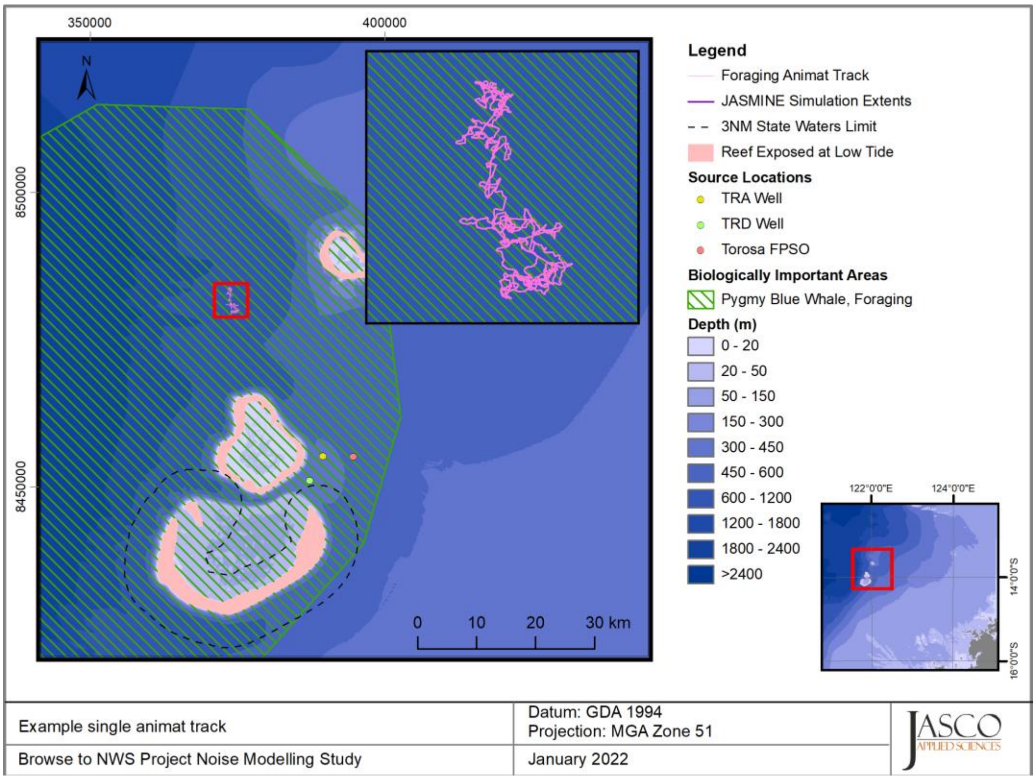

Figure 7. Overview of an example animat track.

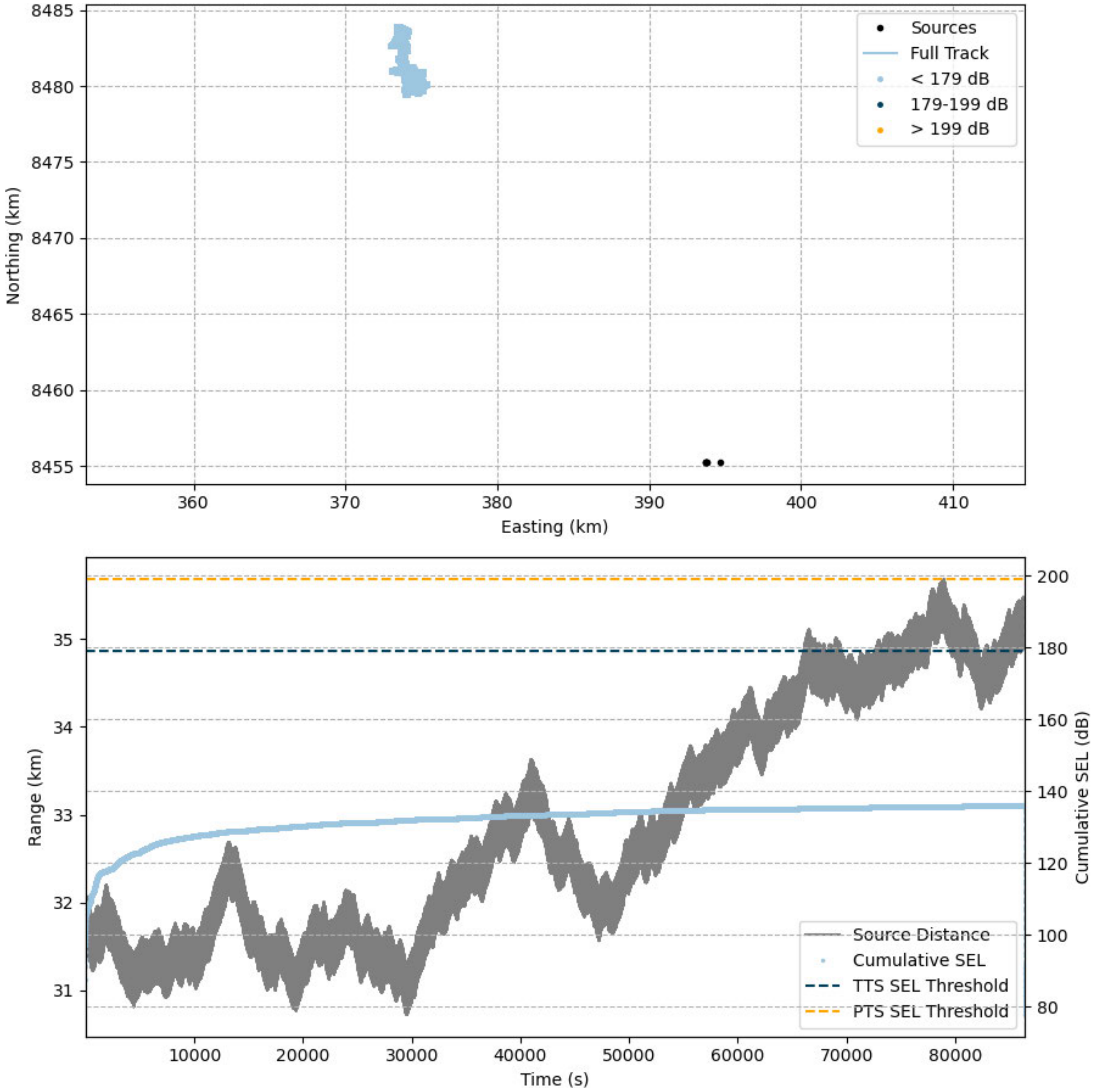

Figure 8. Example animat track from a foraging animat during Scenario 9. TTS and PTS thresholds refer to the criteria for effects of non-impulsive noise exposure on low-frequency cetaceans.

5. Discussion

This animal movement and exposure analysis was done to predict the effects of the development and installation operations for specific scenarios relating to the operation of an MODU under DP at the TRD drill centre, the FPSO at the Torosa location and the aggregate of both activities on both migrating and foraging pygmy blue whales. Exposure ranges for the 120 dB SPL behavioural response threshold aligned with those predicted by acoustic modelling, although the foraging exposure ranges were consistently slightly longer than those calculated for migrating animats. Ranges to PTS and TTS thresholds were minimal for both migrating and foraging behaviours.

Similar to the results presented in the acoustic modelling, exposure ranges for TTS, PTS and behavioural response during the aggregate scenario were not significantly different than during the individual operations (Green et al. 2021). The sites are far enough apart that their summed fields do not contribute to a quantifiable increase in the affected areas.

There was no significant difference between the predicted exposure ranges for northward versus southward migration. While the presence of the reef did influence the movement of the animats near the development area, the distribution of individual animats was not greatly restricted or modified within the TTS, PTS, and behavioural ranges of the sources. The histograms of CPA ranges for these behaviours (Figures 4 and 5) have a similar shape and predict similar exposure ranges, but because the reef effectively blocks a substantial portion of northbound animats from reaching the source area, the number of exposed animats is lower.

For the aggregate scenario (Scenario 9), the probability of exposure (P_{exp}) within $ER_{95\%}$ for the TTS SEL_{24h} threshold ($\leq$0.05 km) varied between 34 and 41%. Within $ER_{95\%}$ for the PTS SEL_{24h} threshold (<0.01 km), P_{exp} varied between 0 and 12%. For behavioural SPL threshold, P_{exp} within $ER_{95\%}$ (<2.3 km) varied between 80 and 90%. These results indicate that some, but not all, animats exposed within the $ER_{95\%}$ were exposed above threshold. This is because the received level at any given position is a function of not only the range to the source but also the vertical position in the water column and the overall path that the animat traversed through the three-dimensional sound field. For example, an animat might approach within the predicted exposure range but if they are traveling more quickly on average than other animats, they may not accumulate as much exposure, or they may be spending more time at depths with quieter sound levels.

5.1. Behavioural effects

Exposure ranges for single exposure metrics, such as the SPL behavioural response criteria, are typically comparable to the predicted acoustic ranges. Acoustic ranges are conservatively calculated using the maximum-over-depth sound fields while exposure ranges account for animats sampling the water column vertically. Because of this, exposure ranges will typically be slightly lower than the corresponding acoustic ranges.

For the behavioural threshold, the maximum $ER_{95\%}$ was 2.78 km. This aligns with the $R_{95\%}$ and R_{max} ranges from static acoustic modelling which were 2.54 km and 4.68 km, respectively. The $ER_{95\%}$ for the 120 dB behavioural threshold was consistently longer for foraging than for migrating pygmy blue whales. This is due to the behavioural profiles of the animats and the way in which they sampled the water column vertically. Migrating animats spend most of their time doing relatively shallow dives that keep them in the upper 30-60 m of the water column, where predicted received levels are lower (see Figure 9).

Although foraging animats may spend a greater amount of time in any given area due to their slower swimming speed and higher course variation (Figure 7), they perform deeper dives than migrating animats (average 312±80m and 30±31m, respectively) and spend more time at those depths.

Therefore, the foraging animats are, on average, exposed to received levels that exceed the behavioural threshold at longer ranges.

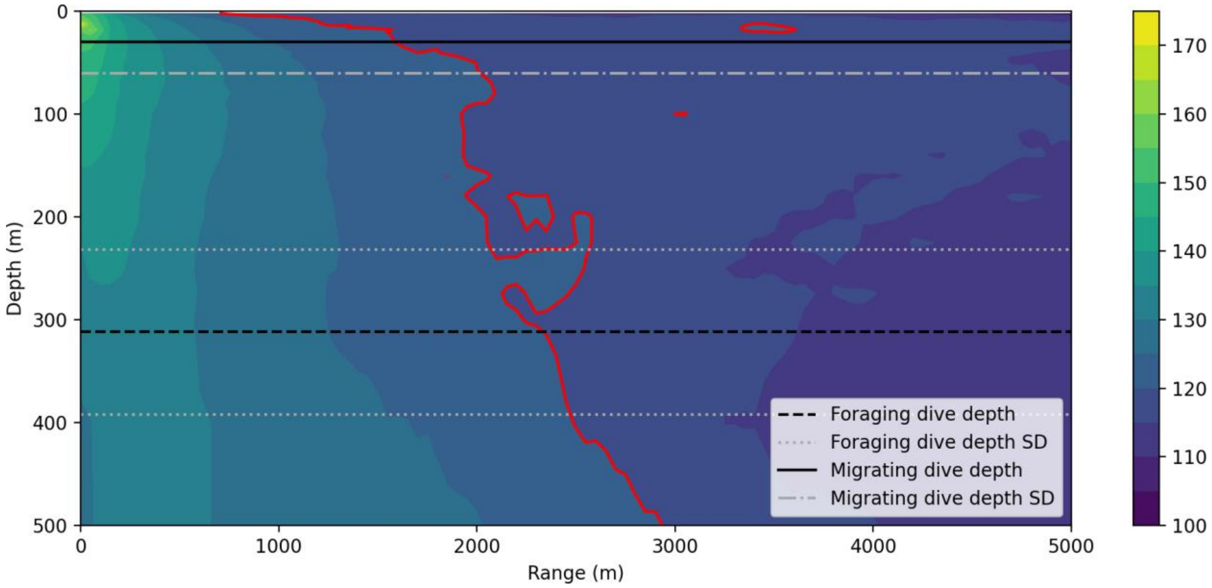

Figure 9. Slice plot showing a profile of the summed SPL sound levels interpolated along a profile centred on the TRD MODU location and extending outward at an azimuth of 45°. The 120 dB contour level is highlighted in red.

5.2. TTS and PTS

Exposure ranges from animal movement modelling for cumulative metrics such as TTS and PTS are typically shorter than those predicted using acoustic propagation modelling because of the shorter dwell time of the moving animats. Results for all scenarios aligned with this pattern, with all exposure ranges being shorter than the corresponding acoustic ranges. In some cases, particularly for Scenario 7 wherein only the FPSO machinery was modelled, there were no animats exposed above threshold, and both PTS and TTS exposure ranges were effectively zero. For the aggregate scenario (Scenario 9), the maximum $ER_{95\%}$ for SEL_{24h} thresholds was ≤0.05 km for TTS and ≤0.01 for PTS, compared to <0.53 km and <0.05 km respectively for the static acoustic modelling. Note that TTS and PTS ranges may be less than the minimum range step in the acoustic model because animats sample the area at a finer resolution.

Glossary

Unless otherwise stated in an entry, these definitions are consistent with ISO 80000-3 (2017).

animal movement modelling

Simulation of animal movement based on behavioural rules for the purpose of predicting an animal's experience of an environment.

auditory frequency weighting

The process of applying an auditory frequency weighting function. In human audiometry, C-weighting is the most commonly used function, an example for marine mammals are the auditory frequency weighting functions published by Southall et al. (2007).

auditory frequency weighting function

Frequency weighting function describing a compensatory approach accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity. Example hearing groups are low-, mid-, and high-frequency cetaceans, phocid and otariid pinnipeds.

cetacean

Any animal in the order Cetacea. These are aquatic species and include whales, dolphins, and porpoises.

continuous sound

A sound whose sound pressure level remains above ambient sound during the observation period. A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decibel (dB)

Unit of level used to express the ratio of one value of a power quantity to another on a logarithmic scale. Unit: dB.

flat weighting

Term indicating that no frequency weighting function is applied. Synonymous with unweighted.

frequency weighting

The process of applying a frequency weighting function.

frequency-weighting function

The squared magnitude of the sound pressure transfer function. For sound of a given frequency, the frequency weighting function is the ratio of output power to input power of a specified filter, sometimes expressed in decibels. Examples include the following:

- *Auditory frequency weighting function*: compensatory frequency weighting function accounting for a species' (or functional hearing group's) frequency-specific hearing sensitivity.
- *System frequency weighting function*: frequency weighting function describing the sensitivity of an acoustic acquisition system, typically consisting of a hydrophone, one or more amplifiers, and an analogue to digital converter.

geoacoustic

Relating to the acoustic properties of the seabed.

hearing group

Category of animal species when classified according to their hearing sensitivity and to the susceptibility to sound. Examples for marine mammals include very low-frequency (VLF) cetaceans, low-frequency (LF) cetaceans, mid-frequency (MF) cetaceans, high-frequency (HF) cetaceans, very high-frequency (VHF) cetaceans, otariid pinnipeds in water (OPW), phocid pinnipeds in water (PPW), sirenians (SI), other marine carnivores in air (OCA), and other marine carnivores in water (OCW) (NMFS 2018, Southall et al. 2019). See **auditory frequency weighting functions**, which are often applied to these groups. Examples for fish include species for which the swim bladder is involved in hearing, species for which the swim bladder is not involved in hearing, and species without a swim bladder (Popper et al. 2014).

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified reference value of that quantity. Examples include sound pressure level, sound exposure level, and peak sound pressure level. For example, a value of sound exposure level with reference to 1 μPa^2 s can be written in the form *x* dB re 1 μPa^2 s.

low-frequency (LF) cetacean

See **hearing group**.

non-impulsive sound

Sound that is not an impulsive sound. A non-impulsive sound is not necessarily a continuous sound.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. PTS is considered auditory injury.

pressure, acoustic

The deviation from the ambient pressure caused by a sound wave. Also called sound pressure. Unit: pascal (Pa).

received level

The level measured (or that would be measured) at a defined location. The type of level should be specified.

reference values

standard underwater references values used for calculating sound **levels**, e.g., the reference value for expressing sound pressure level in decibels is 1 μPa.

Quantity	Reference value
Sound pressure	1 μPa
Sound exposure	1 μPa^2 s
Sound particle displacement	1 pm
Sound particle velocity	1 nm/s
Sound particle acceleration	1 μm/s^2

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium.

sound exposure

Time integral of squared sound pressure over a stated time interval. The time interval can be a specified time duration (e.g., 24 hours) or from start to end of a specified event (e.g., a pile strike, an airgun pulse, a construction operation). Unit: Pa^2 s.

sound exposure level

The level (L_E) of the sound exposure (E). Unit: decibel (dB). Reference value (E_0) for sound in water: 1 μPa^2 s.

$$L_E := 10\log_{10}(E/E_0)\ \text{dB} \ = 20\log_{10}\left(E^{1/2}/E_0^{1/2}\right)\ \text{dB}$$

The frequency band and integration time should be specified. Abbreviation: SEL.

sound field

Region containing sound waves.

sound pressure

The contribution to total pressure caused by the action of sound.

sound pressure level (rms sound pressure level)

The level ($L_{p,\text{rms}}$) of the time-mean-square sound pressure (p_{rms}^2). Unit: decibel (dB). Reference value (p_0^2) for sound in water: 1 μPa^2.

$$L_{p,\text{rms}} := 10\log_{10}(p_{\text{rms}}^2/p_0^2)\ \text{dB} \ = 20\log_{10}(p_{\text{rms}}/p_0)\ \text{dB}$$

The frequency band and averaging time should be specified. Abbreviation: SPL or Lrms.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity. TTS can be caused by noise exposure.

unweighted

Term indicating that no frequency weighting function is applied. Synonymous with flat weighting.

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Appendix A. Animal Movement and Exposure Modelling

Animal movement and exposure modelling considers the movement of both sound sources (if mobile) and animals over time. Acoustic source and propagation modelling are used to generate 3-D sound fields that vary as a function of distance to source, depth, and azimuth. Sound sources are modelled at representative sites and the resulting sound fields are assigned to source locations using the minimum Euclidean distance. The sound received by an animal at any given time depends on its location relative to the source. Because the true locations of the animals within the sound fields are unknown, realistic animal movements are simulated using repeated random sampling of various behavioural parameters. The Monte Carlo method of simulating many animals within the operations area is used to estimate the sound exposure history of the population of simulated animals (animats).

Monte Carlo methods provide a heuristic approach for determining the probability distribution function (PDF) of complex situations, such as animals moving in a sound field. The probability of an event's occurrence is determined by the frequency with which it occurs in the simulation. The greater the number of random samples, in this case the more simulated animats, the better the approximation of the PDF. Animats are randomly placed, or seeded, within the simulation boundary at a specified density (animats/km^2). Higher densities provide a finer PDF estimate resolution but require more computational resources. To ensure good representation of the PDF, the animat density is set as high as practical allowing for computation time. The animat density is much higher than the real-world density to ensure good representation of the PDF. The resulting PDF is scaled using the real-world density.

Several models for marine mammal movement have been developed (Ellison et al. 1987, Frankel et al. 2002, Houser 2006). These models use an underlying Markov chain to transition from one state to another based on probabilities determined from measured swimming behaviour. The parameters may represent simple states, such as the speed or heading of the animal, or complex states, such as likelihood of participating in foraging, play, rest, or travel. Attractions and aversions to variables like anthropogenic sounds and different depth ranges can be included in the models.

The JASCO Animal Simulation Model Including Noise Exposure (JASMINE) was based on the open-source marine mammal movement and behaviour model (3MB, Houser 2006) and used to predict the exposure of animats to sound arising from the anthropogenic activities. Animats are programmed to behave like the species likely to be present in the survey area. The parameters used for forecasting realistic behaviours (e.g., diving, foraging, aversion, surface times, etc.) are determined and interpreted from marine species studies (e.g., tagging studies) where available, or reasonably extrapolated from related species. An individual animat's modelled sound exposure levels are summed over the total simulation duration to determine its total received energy, and then compared to the assumed threshold criteria.

JASMINE uses the same animal movement algorithms as 3MB (Houser, 2006), but has been extended to be directly compatible with JASCO's Marine Operations Noise Model (MONM) and Full Waveform Range-dependent Acoustic Model acoustic field predictions, for inclusion of source tracks, and importantly for animats to change behavioural states based on time and space dependent modelled variables such as received levels for aversion behaviour, although aversion was not considered in this study.

A.1.1. Animal Movement Parameters

JASMINE uses previously measured behaviour to forecast behaviour in new situations and locations. The parameters used for forecasting realistic behaviour are determined (and interpreted) from marine species studies (e.g., tagging studies). Each parameter in the model is described as a probability distribution. When limited or no information is available for a species parameter, a Gaussian or uniform distribution may be chosen for that parameter. For the Gaussian distribution, the user determines the mean and standard deviation of the distribution from which parameter values are drawn. For the uniform distribution, the user determines the maximum and minimum distribution from which parameter values are drawn. When detailed information about the movement and behaviour of a species are available, a user-created distribution vector, including cumulative transition probabilities, may be used (referred to here as a vector model; Houser 2006). Different sets of parameters can be defined for different behaviour states. The probability of an animat starting out in or transitioning into a given behaviour state can in turn be defined in terms of the animat's current behavioural state, depth, and the time of day. In addition, each travel parameter and behavioural state has a termination function that governs how long the parameter value or overall behavioural state persists in simulation.

The parameters used in JASMINE describe animal movement in both the vertical and horizontal planes. The parameters relating to travel in these two planes are briefly described below.

Travel sub-models

- **Direction**– determines an animat's choice of direction in the horizontal plane. Sub-models are available for determining the heading of animats, allowing for movement to range from strongly biased to undirected. A random walk model can be used for behaviours with no directional preference, such as feeding and playing. In a random walk, all bearings are equally likely at each parameter transition time step. A correlated random walk can be used to smooth the changes in bearing by using the current heading as the mean of the distribution from which to draw the next heading. An additional variant of the correlated random walk is available that includes a directional bias for use in situations where animals have a preferred absolute direction, such as migration. A user-defined vector of directional probabilities can also be input to control animat heading. For more detailed discussion of these parameters, see Houser (2006) and Houser and Cross (1999).
- **Travel rate**–defines an animat's rate of travel in the horizontal plane. When combined with vertical speed and dive depth, the dive profile of the animat is produced.

Dive sub-models

- **Ascent rate**–defines an animat's rate of travel in the vertical plane during the ascent portion of a dive.
- **Descent rate**–defines an animat's rate of travel in the vertical plane during the descent portion of a dive.
- **Depth**–defines an animat's maximum dive depth.
- **Reversals**–determines whether multiple vertical excursions occur once an animat reaches the maximum dive depth. This behaviour is used to emulate the foraging behaviour of some marine mammal species at depth. Reversal-specific ascent and descent rates may be specified.
- **Surface interval**–determines the duration an animat spends at, or near, the surface before diving again.

A.1.2. Exposure Integration Time

The interval over which acoustic exposure (L_E) should be integrated and maximal exposure (L_p) determined is not well defined. Both Southall et al. (2007) and the NMFS (2018) recommend a 24 h baseline accumulation period, but state that there may be situations where this is not appropriate (e.g., a high-level source and confined population). Resetting the integration after 24 h can lead to overestimating the number of individual animals exposed because individuals can be counted multiple times during an operation. The type of animal movement engine used in this study simulates realistic movement using swimming behaviour collected over relatively short periods (hours to days) and does not include large-scale movement such as migratory circulation patterns. For this study, a representative 24-hour period was simulated.

Ideally, a simulation area is large enough to encompass the entire range of a population so that any animal that could approach the source during an operation is included. However, there are limits to the simulation area, and computational overhead increases with area. For practical reasons, the simulation area is limited. In the simulation, every animat that reaches a border is replaced by another animat entering at the opposing border—e.g., an animat crossing the northern border of the simulation is replaced by one entering the southern border at the same longitude. When this action places the animat in an inappropriate water depth, the animat is randomly placed on the map at a depth suited to its species definition. The exposures of all animats (including those leaving the simulation and those entering) are kept for analysis. This approach maintains a consistent animat density and allows for longer integration periods with finite simulation areas.

A.1.3. Seeding Density and Scaling

Seeding density refers to the spatial sample rate, in units of animats/ km^2, used in the simulation. It is not related to the real-world animal density, but rather is a model parameter that controls the how samples are drawn from the model space. The minimum required seeding density for any given project depends on several factors such as bathymetry, source characteristics, and the behavioural profile of the animats, with the main constraint being computation time and resources. Seeding density is adjusted as needed based on model conditions specific to a project or project area.

In the present study, the exposure criteria for continuous sounds were used to determine the number of animats exceeding exposure thresholds. To generate statistically reliable probability density functions, all simulations were seeded with an animat density of 3 animat/km^2 over the entire simulation area. The modelling results are not related to real-world pygmy blue whale densities and the number of real-world animals potentially exposed was not calculated.

Appendix D – Browse TRB and TRD Subsea Manifold LF Cetacean Noise Exposure Assessment (AMOG 2022)

Browse TRB & TRD Subsea Manifold LF Cetacean Noise Exposure Assessment

Browse Underwater Noise Modelling

Woodside Energy Limited

Engineering solutions

Engineering solutions

10th November 2022

Browse TRB & TRD Subsea Manifold LF Cetacean Noise Exposure Assessment

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Browse Underwater Noise Modelling

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AMOG Consulting

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Page	**Revision**	**Date**	**Comment**
All	Draft B	10th November 2022	Initial issue for client comments.

EXECUTIVE SUMMARY

This report details the predictions of the spatial extent of underwater noise generated by operating subsea manifolds at WEL's two proposed Browse Basin project sites, TRB & TRD in the Torosa region. The spatial extents are reported against international accepted maximum noise level criteria for low frequency (LF) cetaceans.

Multiple subsea manifold scenarios were assessed including varying the numbers of wellheads at each manifold and using a sound 'mitigated' version of the manifolds. All scenarios assumed the manifolds were operating continuously.

The Torosa region represents a particularly challenging scenario for underwater sound predictions due to the presence of limestone and steeply varying bathymetry. Additionally, the water depth, range and frequency of noise source is to be considered when selecting the most appropriate prediction method.

To address these project specific challenges, AMOG developed a hybrid model (normal-mode with complex root solver & parabolic equation solver) which was benchmarked against measured data where possible in different frequency ranges. This benchmarked hybrid approach is now suitable for assessing any future noise source effects including different noise source frequencies and locations.

For the scenarios modelled, it was concluded that the behavioural change SPL threshold limit produced the largest R_{MAX} and $R_{95\%}$ distance measurements, as opposed to SEL threshold limits.

For the scenarios investigated:

- The behavioural change threshold (SPL) limits were at most ~200 m vertically above the seabed manifold with a maximum radial extent of ~360 m.
- The TTS (Temporary) spatial threshold limits (defined by SEL) were at most 100 m vertically above the seabed manifold with a maximum radial extent of 60 m and all considerably smaller than the above SPL limits. These can be found in the report (Table 4).
- The PTS (Permanent) spatial threshold limits (defined by SEL) were at most 10 m vertically above the seabed manifold with a maximum radial extent of 10 m also. These can be found in the report (Table 5).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

AMOG Consulting (AMOG) have been engaged by Woodside Energy Limited (WEL) under PO 4510734059 to conduct underwater acoustic modelling of sound levels associated with the operation of choked-flow wells at two manifold locations in the Browse Basin offshore Western Australia.

1.1 SCOPE OF WORK

This report details the underwater acoustic modelling undertaken to assess the impact of drilling operations at Browse on low-frequency (LF) cetaceans. The two sites under analysis labeled TRB and TRD, which are located in the Torosa region of the Browse Basin, as shown in Figure 1.

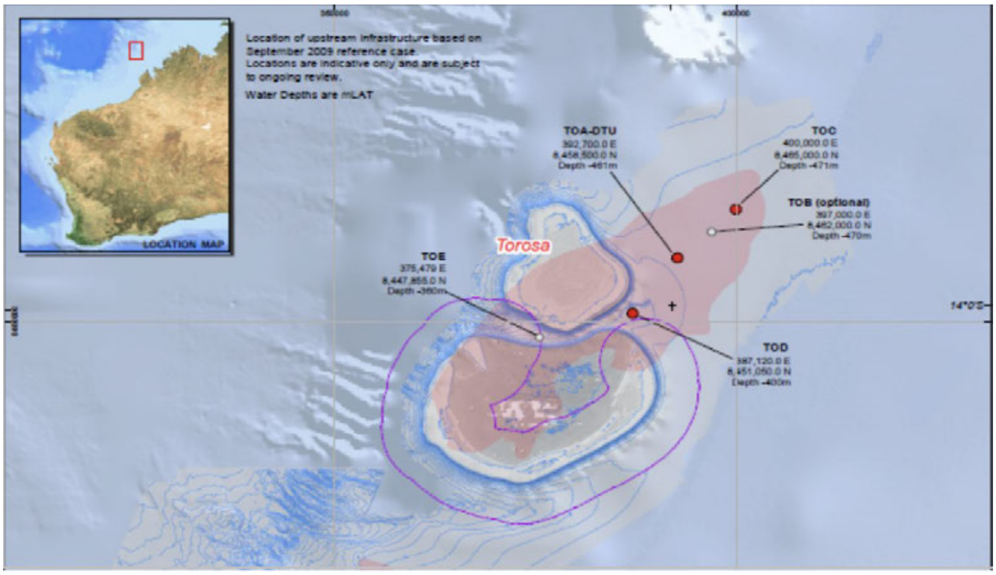


Figure 1: Browse Basin Wellhead Manifold Locations, [1]

1.2 DOCUMENT OUTLINE

This report is arranged as follows:

- Section 1 presents the background to the work;
- Section 2 details the assessment criteria, scenarios, noise sources and site locations considered in the modelling;
- Section 3 details the model selection and benchmarking;
- Section 4 presents the Sound Pressure Level results;
- Section 5 presents the Sound Exposure Level results;
- Section 6 presents the conclusions from the study;
- Section 7 lists the references used, and;
- Section 8 contains the appendices, including the benchmarking results.

1.3 NOMENCLATURE

Definitions of common underwater acoustic terminology are provided in Appendix A.

1.3.1 Acronyms And Abbreviations

AMOG	AMOG Consulting
ASB	Above SeaBed
dB	Decibel
FEED	Front End Engineering Design
PTS	Permanent Threshold Shift
SEL	Sound Exposure Level
SPL	Sound Pressure Level
TRB	Torosa Site “B”
TRD	Torosa Site “D”
TTS	Temporary Threshold Shift
WEL	Woodside Energy Limited

2 STUDY BASIS

The two manifolds are located in areas where the seabed is non-uniform and consist of different seabed geology (a mixture of sand and limestone), which have varying hydro-acoustic properties. This section will detail each scenario to be modelled, the seabed properties surrounding each site and the noise sources utilised.

2.1 SCENARIO LIST

The scenario list is comprised of several scenarios involving wellhead operation at two different wellhead manifolds at site locations defined as TRD and TRB. Table 1 presents the scenario list.

Table 1: Browse Scenario List and Description

Scenario #	Location	Number of Wellheads Operating	Mitigated or Unmitigated Noise Source
1	TRD	3	Unmitigated
2	TRD	6	Unmitigated
3	TRD	6	Mitigated
4	TRB	6	Unmitigated
5	TRB	6	Mitigated

All scenarios assume 24-hour continuous operation for the calculation of SEL.

2.2 SITE LOCATIONS

Bathymetry data was processed and the contour map for the sites are presented in Figure 2. The seabed material information was provided in [9] and is presented in Figure B-1 (Appendix B).

The TRB site is located in deep water (~460 m) and surrounded by a slightly sloped sandy seabed. The bathymetry doesn’t vary largely around the TRB site.

The TRD site is located in relatively deep water (~390 m) but near a steep, limestone reef where the bathymetry varies with range and azimuth.

Appendix B details the site information inputted into the hydro-acoustic models, as well the key modelling assumptions for TRB and TRD.

In order to generate a 3D sound level field around TRD, azimuths (or cross-sections) were selected to model. The results were then used to calculate the rest of the sound field. Figure 2 presents the Browse Basin, with TRB and TRD sites highlighted, as well as the directions modelled for TRD. The location of where a CTD profile was taken is also highlighted (see Appendix B, Section B.1.1.2).

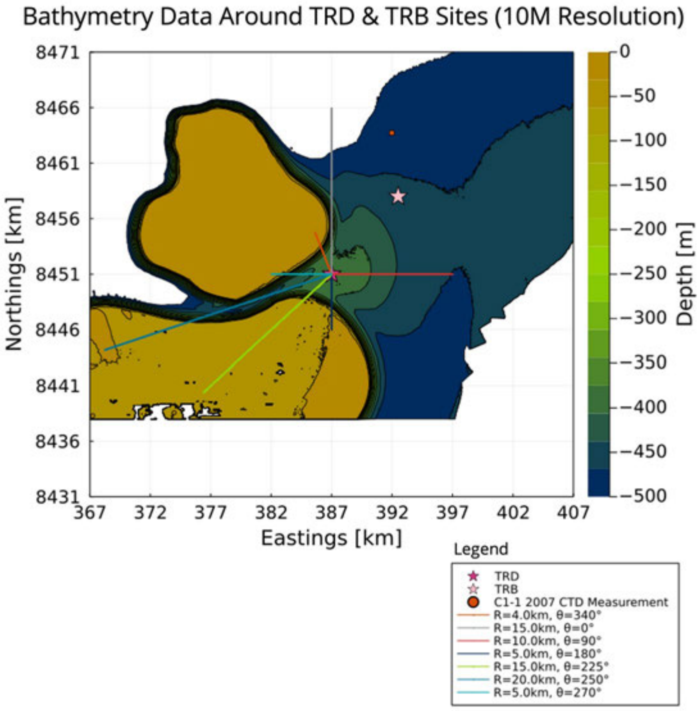


Figure 2: Browse Basin Contour Map with selected azimuths for TRD

2.3 NOISE SOURCES

The one-third octave noise spectra used for modelling in the scenarios detailed in Table 1 are presented below. WEL provided two noise source spectrums [15], from simulated data based on a pre-FEED, of one operating wellhead at a typical noise level (unmitigated) and a reduced noise level (mitigated). Both noise source spectrums are shown in Figure 3 below.

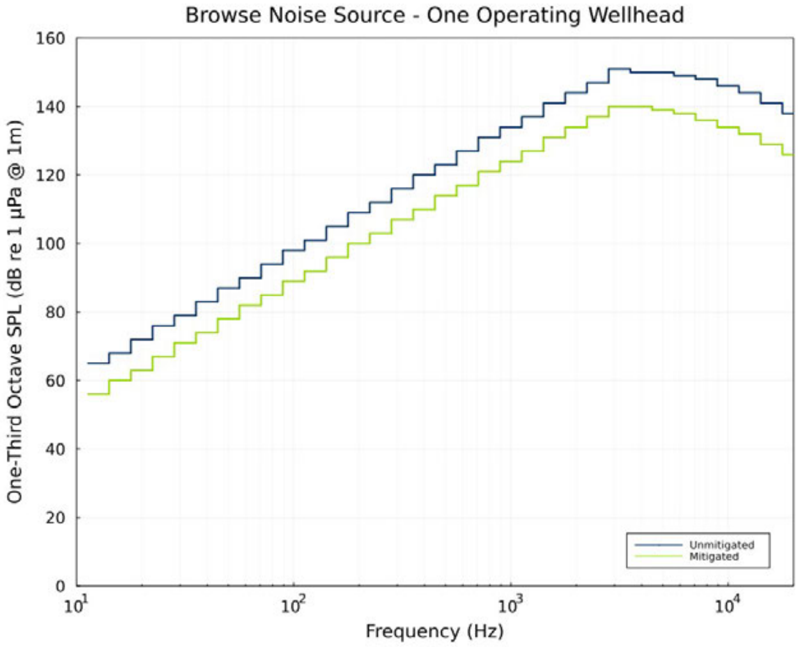


Figure 3: One Operating Wellhead (Unmitigated and Mitigated Profiles)

2.3.1 Scenario Noise Spectra

The noise spectra for each scenario (defined in Table 1) were specified as follows for this study:

1. Scenario #1: Logarithmic addition of three unmitigated wellhead noise sources (TRD)
2. Scenario #2: Logarithmic addition of six unmitigated wellhead noise sources (TRD)
3. Scenario #3: Logarithmic addition of six mitigated wellhead noise sources (TRD).
4. Scenario #4: As per Scenario #2 but for TRB (six combined unmitigated noise sources)
5. Scenario #5: As per Scenario #3 but for TRB (six combined mitigated noise sources)

The noise spectra to be used to model each scenario is presented in Figure 4.

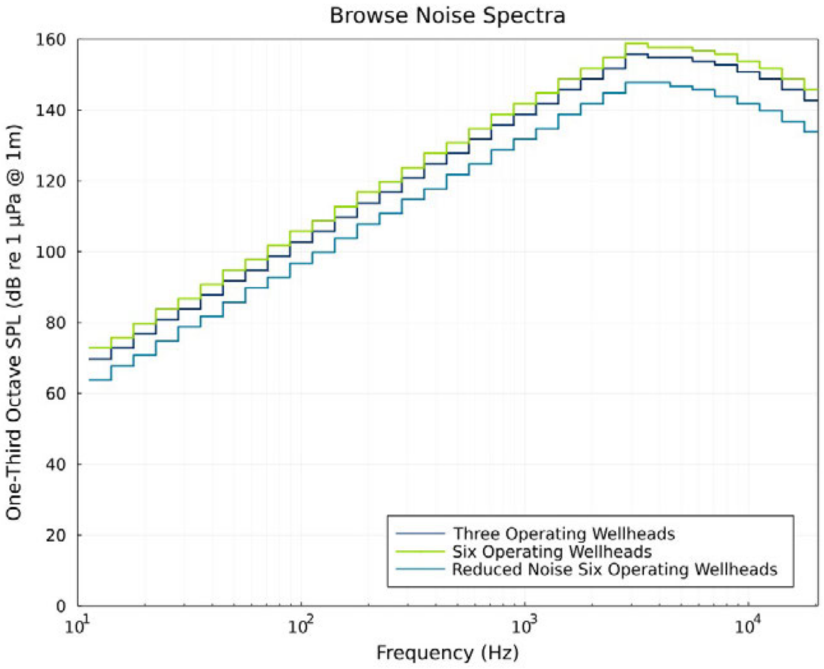


Figure 4: Browse Noise Spectra

2.4 ASSESSMENT CRITERIA

A summary of the assessment criteria is provided in this section.

2.4.1 Hearing Groups

Hearing Groups are defined as per NOAA Fisheries Guidance [6], shown in Table 5.

Table 2: Hearing Groups

Hearing Group[1]	Frequency Range
Low-frequency (LF) cetaceans	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans	150 Hz to 160 kHz
High-frequency (HF) cetaceans	275 Hz to 160 kHz
Phocid pinnipeds (PW) (underwater)	50 Hz to 86 kHz
Otariid pinnipeds (OW) (underwater)	60 Hz to 39 kHz

Notes:
1. For further definition of each group refer to Table 5 of [6].

Only LF cetaceans were considered within the scope of work.

The model implemented only considered up to 20 kHz frequencies, as it was the maximum frequency provided for the wellhead operation noise source spectra.

2.4.2 Sound Pressure Level (SPL)

An unweighted SPL of **120 dB** re 1μPa was used as the behavioural disruption limit for continuous noise, as per NOAA Fisheries Technical Guidance [7].

2.4.3 Sound Exposure Level (SEL)

Sound exposure is a measure of energy that takes into a type of metric, which is a function of noise levels and duration. Due to the nature of the sound pro-les (continuous, not impulsive), a frequency weighted SEL for Permanent Threshold Shift Onset of **199 dB** (re 1μPa^{2}s 24 hr) and Temporary Threshold Shift Onset of **179 dB (**re 1μPa^{2}s 24 hr) was assumed for the Low-frequency (LF) cetaceans hearing group [7].

The sound exposure levels where presented were calculated based on a one-third octave weighting from Table ES2 of [7].

3 MODEL SELECTION AND BENCHMARKING

3.1 MODEL SELECTION

3.1.1 Factors Of Frequency, Water Depth, Range, Bottom Slope & Source Location

There are several types of acoustic models that can be used to predict the propagation of underwater acoustic noise. These fall into four main categories:

- Ray methods,
- Parabolic equation (PE) model,
- Normal-mode, and,
- wavenumber integration models.

The preferred model is primarily dependent on the frequency of the noise source, the bathymetry and the desired range to be modelled [11]. Figure 5 demonstrates the limits of the various acoustic noise models for sites involving shallow water depths (< 100 m), such as those seen for the TRD site.

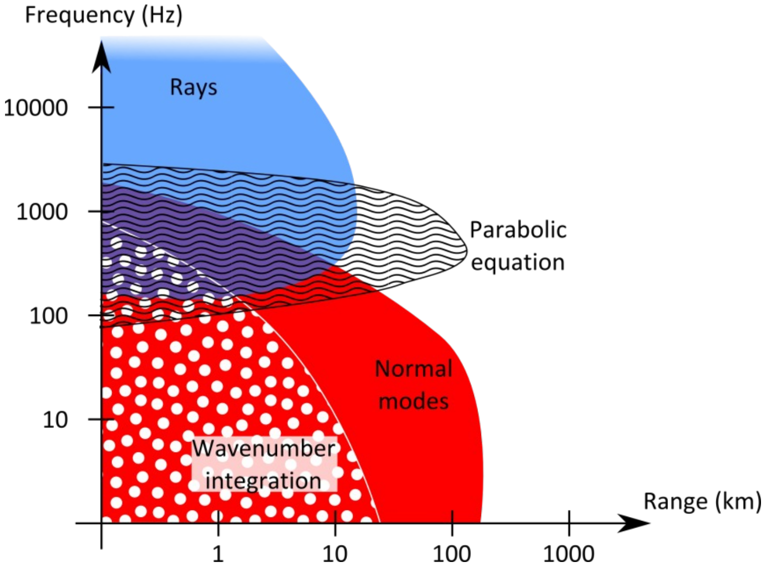


Figure 5: Outline of frequency and range domain for shallow water acoustic noise models, adapted from [11].

The modelling of noise for the two Browse sites is characterised by the following:

- A combination of low frequencies, below 1500 Hz, and high frequencies of up to 19 kHz,
- Moderate ranges of up to 20km,
- A flat, sandy seabed for the TRB site, but a steep bathymetry for the TRD site with sandy and limestone (calcarenite) seabeds, and;
- Noise sources close to the seabed.

The inclusion of a site with steep bathymetry changes limits the choice of models to those capable of range-dependent modelling. Range-dependent models can depict noise transmission over seabeds with large variations in bathymetry. Wavenumber integration models are incapable of modelling varying bathymetry and as such were not further considered for this study [5]. Ray methods are capable of range-dependent modelling but they ignore diffraction and modal effects [1] which are significant for the TRD site, as such, these methods also were not considered for this study. This may introduce significant errors for modelling of the TRD site and ray methods were not used as a result.

3.1.2 Factor Of Limestone Seabed

The inclusion of limestone seabeds for the TRD site adds an additional modelling complexity. Limestone is a hard elastic material which absorbs more sound that fluid-like sandy seabeds that are typically easier to model. The added attenuation of the limestone is due to the ability of elastic seabeds to propagate secondary acoustic waves due to having a non-zero shear modulus. As a result, when acoustic waves are reflected off an elastic seabed, some of the acoustic energy is dissipated as shear waves. Fluid seabeds, such as sand, have no shear modulus and cannot support shear waves resulting in less noise attenuation [5].

AMOG selected KRAKENC for modelling of noise propagation for low frequencies. KRAKENC is a normal-mode model that uses a complex root finder in order to capture the portion of the sound that is absorbed by elastic seabeds. KRAKENC supports range-dependent modelling of elastic seabeds with steep bathymetry. KRAKENC also has the ability to capture surface waves at the interface between the noise source and a solid seabed, known as Scholte waves. Scholte waves are more likely to occur for noise sources near the seabed, as is the case for both sites modelled here. The excitation of these surface waves along the seabed may affect the overall transmission loss at low frequencies. This Scholte wave interaction is likely to develop over a limestone seabed due to its elasticity [12]. Additionally, KRAKENC is able to model the expected rapid attenuation of low frequency noise, for sharp bathymetry angles and shallow water depths, over limestone seabeds [13].

RAMGEO was the parabolic equation (PE) model selected for high frequency noise modelling. RAMGEO is capable of accurately predicting high frequency transmission loss of noise over sand and limestone seabeds, for range-dependent and problems [5,12]. RAMGEO does not support elastic seabeds and as such they are modelled as fluids with equivalent geo-acoustic properties [1].

RAMGEO was preferred to KRAKENC for higher frequencies as it is more robust and computationally efficient. RAMGEO is unable to accurately predict the acoustic field at very steep angles, resulting in an underestimation of the noise level directly above the noise source. As a result, a spherical transmission loss assumption directly above the noise source was used to provide conservative noise levels in this region for high frequencies [1].

3.1.3 Model Frequency Bounds

A convergence study was conducted to find the frequency limits of KRAKENC and RAMGEO for the TRB site. This was used to determine the overlapping frequencies for which both KRAKENC and RAMGEO are in agreement, based on the guideline presented in Figure 5. RAMGEO fails to predict noise transmission for low frequencies of < 100 Hz, as described in [5,11], with accuracy improving at higher frequencies.

Conversely, KRAKENC is more suited to noise modelling of lower frequencies and will start to diverge for high frequencies. For this site, the upper limit for KRAKENC convergence was 5000 Hz. It was decided based on the guidelines for the limits of different noise model, presented in Figure 1, and the internal convergence study by AMOG, to use KRAKENC for frequencies up to 1-2000 Hz depending on the local bathymetry and RAMGEO for higher frequencies.

3.2 BENCHMARKING

KRAKENC and RAMGEO are both open source codes available from the OALIB acoustic toolbox [14]. User inputs, pre-processing for both models and post-processing of results were implemented using AMOG's in-house software. Benchmarking of the modelling inputs for both KRAKENC and RAMGEO against published data of transmission loss over limestone and sandy seabeds [1,5,13]. Example figures from AMOG's internal benchmarking of range-dependent modelling for KRAKENC and RAMGEO for elastic seabeds can be found in Appendix D.

4 SPL LIMIT IDENTIFICATION

4.1 SUMMARY

SPL [dB re: 1μPa] for each scenario was calculated by combining the sound level from each frequency (defined as *broadband* SPL). The distance measurements reflect the maximum broad-banded sound level through the water column (for radial distance from source) or per direction (distance ASB). An explanation of the distance measurements is given in Appendix A.

Maximum distance thresholds (R_{MAX}) and 95% of furthest points distance thresholds ($R_{95\%}$) of SPL [dB re: 1μPa] levels are provided in Table 3 for each of the five scenarios.

Table 3: Distance Measurements to 120 dB SPL threshold level [dB re 1μPa]

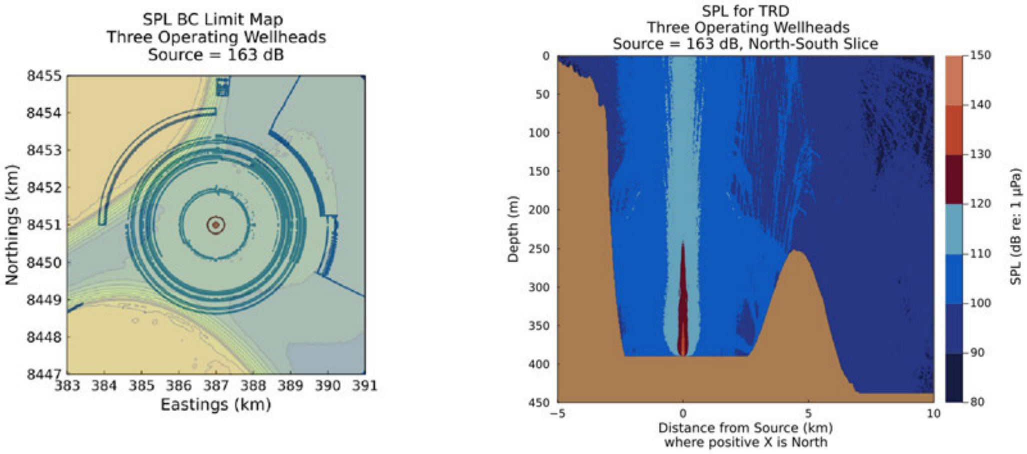
Site	TRD			TRB	
Scenario #	1	2	3	4	5
Scenario Description	3 wellheads	6 wellheads	6 mitigated wellheads	6 wellheads	6 mitigated wellheads
Radial Distance From Source [m], to nearest 10 m					
R_{MAX}	230	360	100	340	90
$R_{95\%}$	220	330	90	330	80
Distance ASB [m], to nearest 10 m					
R_{MAX}	140	200	60	190	50
$R_{95\%}$	130	190	50	180	50

4.2 SPL SOUND MAPS

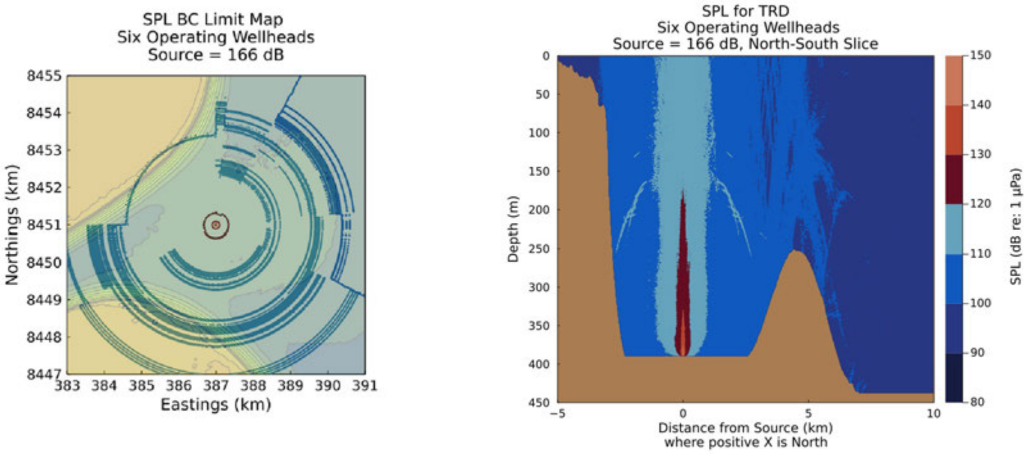
SPL [dB re 1μPa] sound maps are shown for each scenario in Figures 6 and 7, where a North-South cross-section is shown for the elevation view. Appendix C contains the additional cross-sections modelled.

The red contour lines in the SPL map plots indicate all regions above the 120 dB behavioural disruption limit.

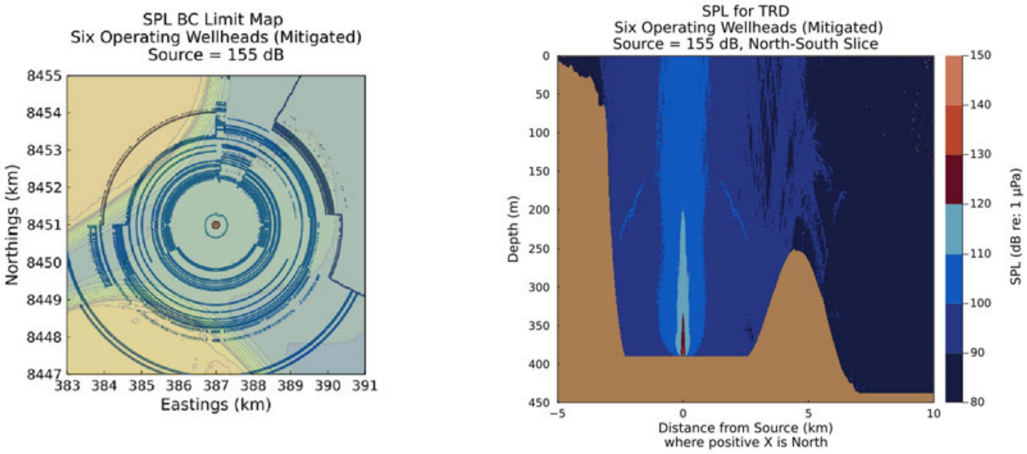
4.2.1 TRD



(a) Scenario #1 Three Operating Wellheads



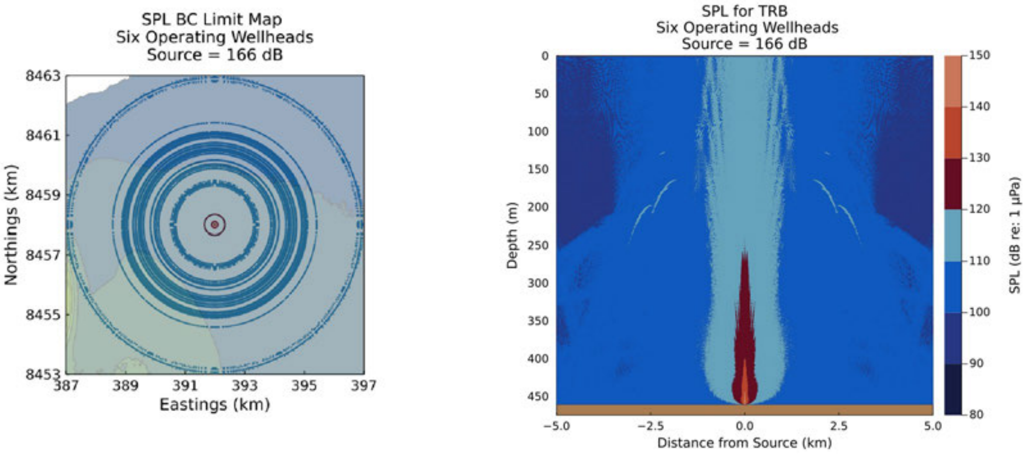
(b) Scenario #2 Six Operating Wellheads



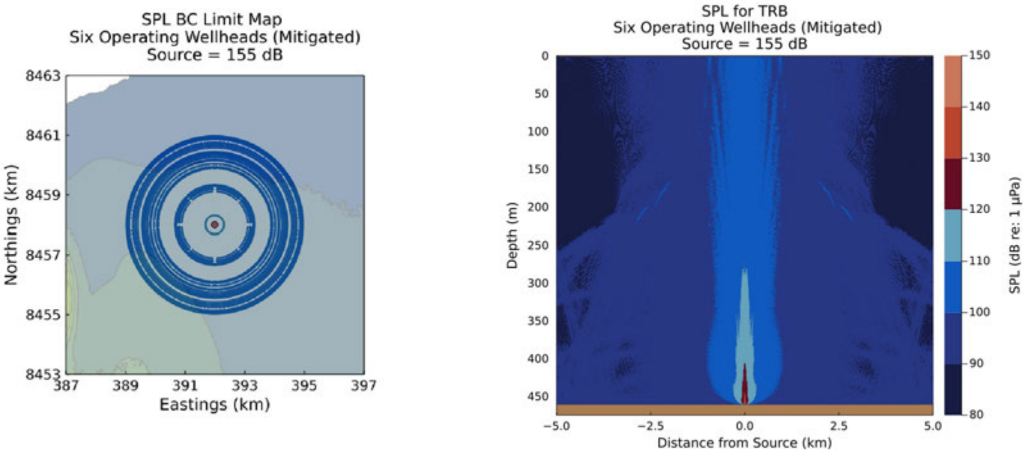
(c) Scenario #3 Six Reduced-Noise Operating Wellheads

Figure 6: SPL Map [dB re 1μPa] during TRD Scenarios

4.2.2 TRB



(a) Scenario #4 Six Operating Wellheads



(b) Scenario #5 Six Reduced-Noise Operating Wellheads

Figure 7: SPL Map [dB re 1μPa] during TRB Scenarios

5 SEL LIMIT IDENTIFICATION

5.1 SUMMARY

Radial distance thresholds of SEL (Frequency Weighted Sound Exposure Levels over a 24hr period) are provided in Table 4 (TTS) and 5 (PTS) for each scenario.

An explanation of the distance measurements is given in Appendix A.

Table 4: Distance Measurements to SEL TTS threshold levels [dB re 1µPa^{2}s 24 hr]

Site	TRD			TRB	
Scenario #	1	2	3	4	5
Scenario Description	3 wellheads	6 wellheads	6 mitigated wellheads	6 wellheads	6 mitigated wellheads
Radial Distance From Source [m], to nearest 10 m					
R_{MAX}	70	100	20	100	20
$R_{95\%}$	70	90	20	90	20
Distance ASB [m], to nearest 10 m					
R_{MAX}	40	60	20	60	20
$R_{95\%}$	40	60	20	50	10

Table 5: Distance Measurements to SEL PTS threshold levels [dB re 1µPa^{2}s 24 hr]

Site	TRD			TRB	
Scenario #	1	2	3	4	5
Scenario Description	3 wellheads	6 wellheads	6 mitigated wellheads	6 wellheads	6 mitigated wellheads
Radial Distance From Source [m], to nearest 10 m					
R_{MAX}	< 10	< 10	< 10	< 10	< 10
$R_{95\%}$	< 10	< 10	< 10	< 10	< 10
Distance ASB [m], to nearest 10 m					
R_{MAX}	< 10	< 10	< 10	< 10	< 10
$R_{95\%}$	< 10	< 10	< 10	< 10	< 10

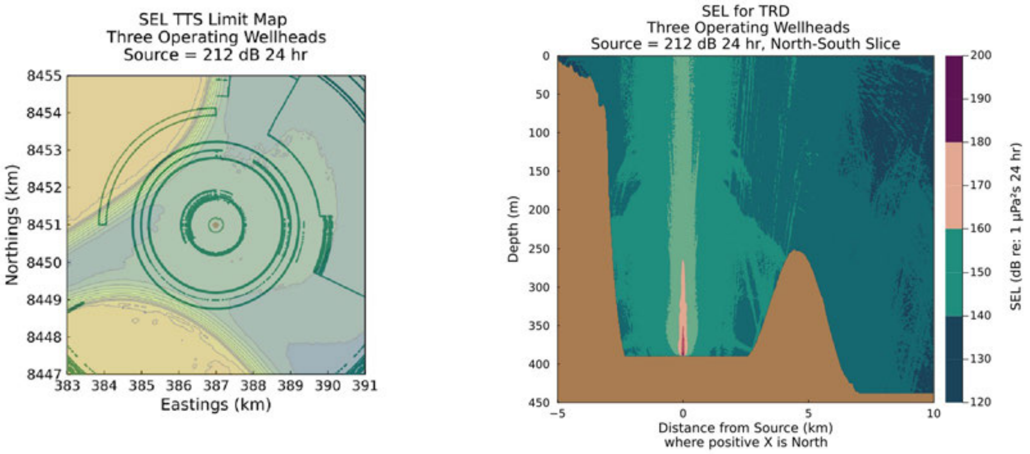
The SEL falls below PTS thresholds for all scenarios within the first 10 m. As such, the SEL sound limit maps for PTS aren't presented in the following section.

5.2 SEL SOUND MAPS

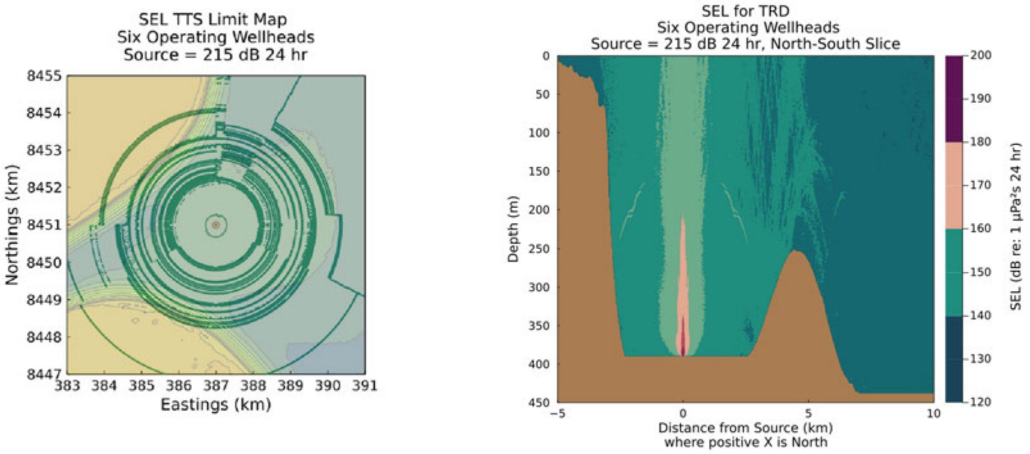
SEL [dB re 1μPa^{2}s 24 hr] sound maps are shown for each scenario in Figures 8 and 9, where a North-South cross-section is shown for the elevation view. The cross-sections that are not presented in this Section are shown in Appendix C.

The darker pink-purple contour lines in the SPL plan map plots indicate all regions above the 179 dB [dB re 1μPa^{2}s 24 hr] TTS SEL limit corresponding to the LF cetacean temporary hearing loss criteria.

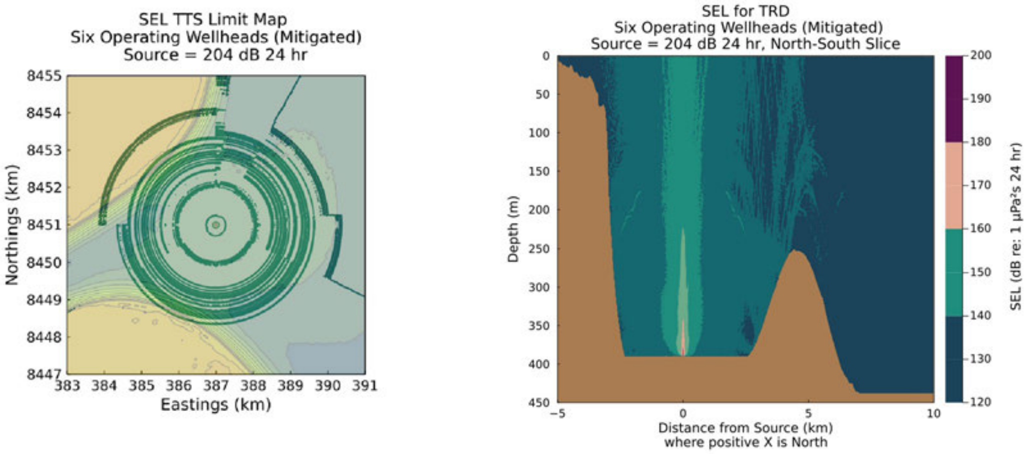
5.2.1 TRD



(a) Scenario #1 Three Operating Wellheads



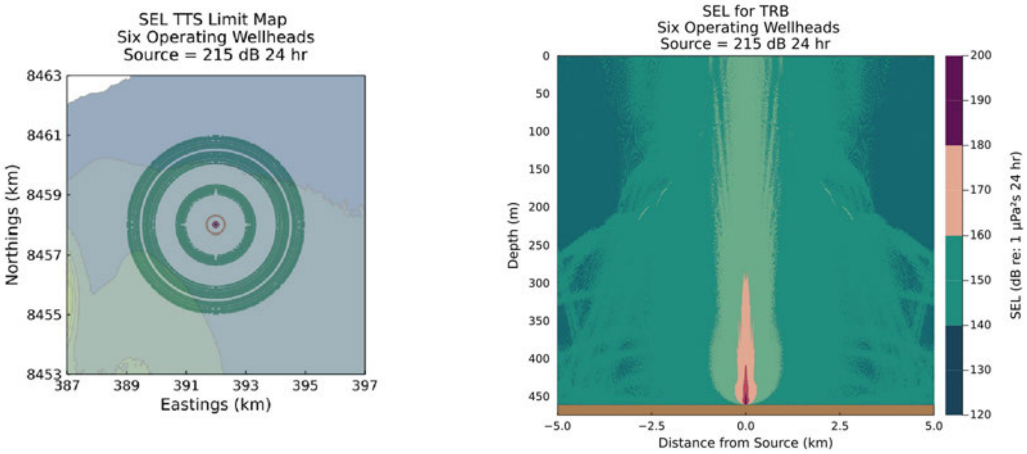
(b) Scenario #2 Six Operating Wellheads



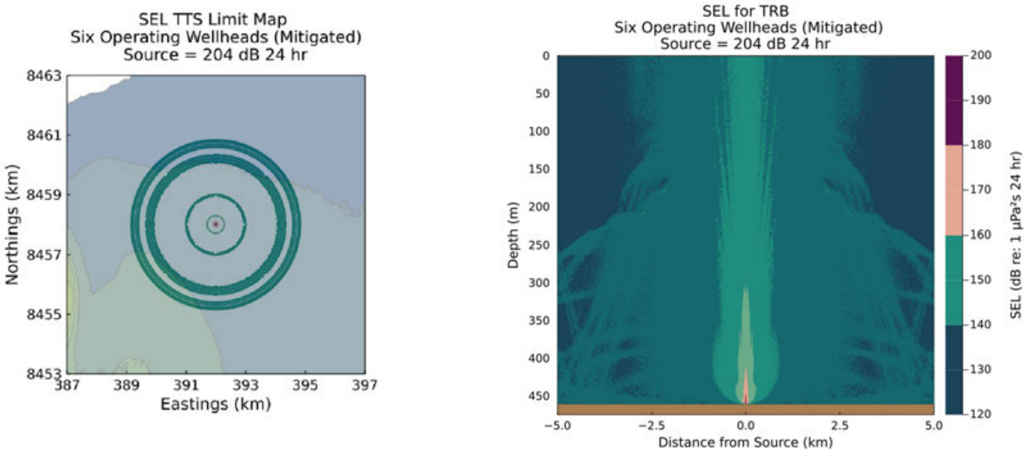
(c) Scenario #3 Six Operating Wellheads (Mitigated)

Figure 8: SEL Map [dB re 1µPa^{2}s 24 hr] during TRD Scenarios

5.2.2 TRB



(a) Scenario #4 Six Operating Wellheads



(b) Scenario #5 Six Operating Wellheads (Mitigated)

Figure 9: SEL Map [dB re 1µPa^{2}s 24 hr] during TRB Scenarios

6 CONCLUSIONS

A combination of modelling techniques was used to model the sound propagation from the TRB and TRD manifold locations in the Browse Field. This combination of modelling techniques was adopted to best capture the impact of complex bathymetry, non-uniform seabed geology and a noise source on the seabed. The key findings were:

1. The combination of normal mode (for low frequencies) and parabolic equation (for high frequencies) methods were required and benchmarked to demonstrate their applicability for the characteristics of this site.
2. The SPL criteria of 120 dB re 1μPa was found to be governing for all scenarios at both the TRB and TRD location.
3. The maximum radial distance from the noise source was calculated as 360 m (R_{MAX}) with an $R_{95\%}$ of 330 m for Scenario 2 (6 operating wellheads at TRD). This scenario also had the greatest vertical distance from the noise source of 220 m R_{MAX}.
4. The impact of the mitigated 6 wells operating noise source and only three wellheads operating at TRD predicted a reduction of R_{MAX} to 100 m and 230 m respectively.
5. The maximum radial distances for the SEL criteria were 100 m for the TTS criteria (179 dB re 1μPa^{2}s 24 hr) but under 10 m for the PTS criteria (199 dB dB re 1μPa^{2}s 24 hr), for the noise sources that exceed this value at the source.

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8 APPENDICES

TABLE OF CONTENTS - APPENDICES

APPENDIX A DEFINITIONS

APPENDIX B MODEL INPUTS

APPENDIX C TRD ADDITIONAL RESULTS

APPENDIX D MODEL BENCHMARKING

LIST OF TABLES - APPENDICES

LIST OF FIGURES - APPENDICES

Appendix A Definitions

A.1 Definitions

Absorption	The process in which a material takes in sound energy, rather than reflecting it. Absorbed sound energy is converted to heat.
Attenuation	A measure of the energy loss of sound propagation in a given medium.
Azimuth	A horizontal angle, measured clockwise from North.
Bandwidth	The range of frequencies over which a sound occurs.
Broadband Sound Level	A single value that is the result of combining all sound levels across frequency bands. It is typically presented in dB. Broadband Sound Level = $10*\log_{10}(\Sigma(10^{SPL/10}))$, where SPL represents the individual sound levels across frequency bands.
bar	A unit of pressure, approximately equivalent to atmospheric pressure at sea level. 1bar = 100kPa.
Cavitation	The formation and collapse of vapour bubbles due to rapid changes of pressure. Commonly formed by propellers. The collapse of the bubbles creates shock waves which generate noise.
Cetacean	An aquatic group of mammals comprising whales, dolphins and porpoises.
Decade	A unit for measuring frequency ratios on a logarithmic scale, with one decade corresponding to a ratio of 10 between two frequencies. For example, 10Hz to 100Hz is a decade.
Decidecade	One tenth of a decade.
Decibel (dB)	A logarithmic unit used to express the intensity of sound.
Frequency	The number of occurrences of a repeating event per unit of time. Typically measured in Hertz (Hz), where 1 Hz = 1 cycle per second.
Hearing Group	Groups of marine species with similar hearing ranges.
LF Cetacean	A subset of cetaceans (baleen whales) capable of hearing low frequencies.
Octave	The interval between a sound and one with double its frequency.
One-third Octave	One third of an octave, approximately equivalent to one decidecade.
Permanent Threshold Shift (PTS)	Acute changes in hearing sensitivity resulting from excessive noise exposure that does not recover over time.
R_{MAX}	The maximum radial distance (from the source) to the specified sound limit over all azimuths/directions.
$R_{95\%}$	The radial distance to the specified sound limit after the 5% farthest points are excluded.
Sound Pressure Level (SPL)	The ratio of a sound pressure relative to a reference sound pressure. In underwater acoustics, the standard unit of acoustic pressure is the microPascal (μPa). Therefore, the amplitude of a sound pressure is

	compared to 1 μPa so that the sound pressure level (SPL) is defined as: $SPL = 20*\log_{10}(p/1\ \mu Pa)$ where p is the sound pressure determined in a specified way. The units of SPL are thus dB re 1 μPa. [as per https://www.ncbi.nlm.nih.gov/books/NBK221261/]
Sound Speed Profile	The speed of sound through a medium, expressed as a function of depth below an interface (for example, the sea surface).
Spectrum	A representation of a sound's intensity as a function of frequency.
Temporary Threshold Shift (TTS)	Acute changes in hearing sensitivity resulting from excessive noise exposure that recover over time.
Transmission Loss	The reduction in sound intensity (measured in dB) due to geometric spreading and sound absorption as a sound propagates through a medium.

A.2 Method for Calculating R_{MAX} and $R_{95\%}$ Distances Measured From SPL and SEL Maps

Figure A-1 presents an example of how the maximum radial distance (R_{MAX}) and radial distance where the 5% furthest points were excluded ($R_{95\%}$) are measured.

When calculating R_{MAX} and $R_{95\%}$ for radial distance, the sound level was combined into a broadband sound level for each depth throughout the water column. The maximum broadband sound level throughout the water column was then determined and was used to generate the plan view SPL and SEL maps.

When calculating R_{MAX} and $R_{95\%}$ for distance above seabed (ASB), the water column directly above the source was utilised.

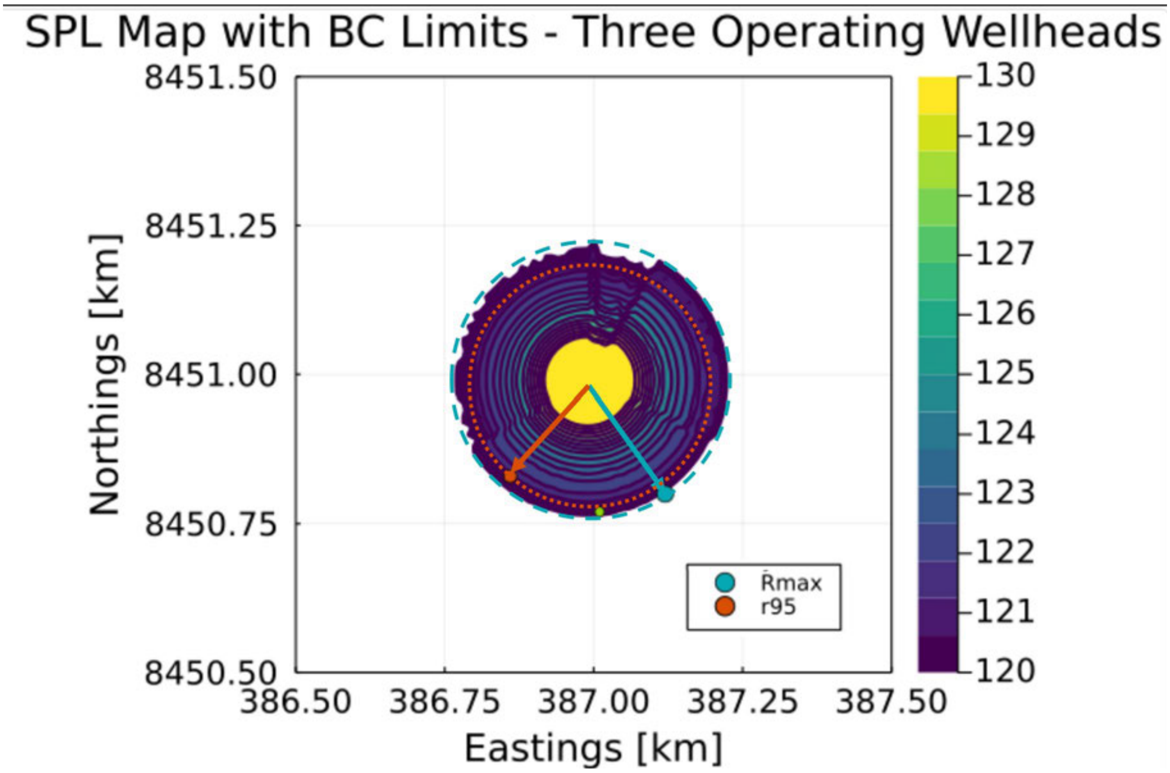


Figure A-1: SPL [dB re 1μPa] Map with explanation of distance measurements

Appendix B Model Inputs

B.1 Summary of Primary Inputs

B.1.1 Environmental Inputs

B.1.1.1 Site Locations And Water Depths

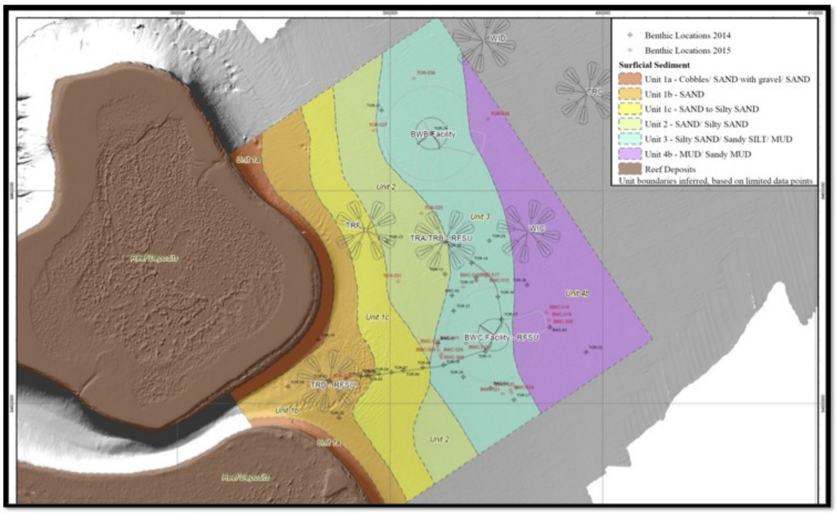


Figure B-1: Browse Site Map Showing Seabed Type [9]

The geographical locations of TRD and TRB were determined from Figure B-1, and are presented in Table B-1.

Table B-1: Site Location List

Site Name	Water Depth^{2} [m]	Eastings^{1,3} [m]	Northings^{1,3} [m]
TRB	461	387100	8451000
TRD	390	392600	8457700

Notes:
1. In reference to WGS84 Datum
2. Rounded to nearest 1
3. Rounded to nearest 100

B.1.1.2 Water Column Characteristics

Temperature and salinity through water column measurements in various locations around the Browse Basin were recorded and reported by RPS MetOcean for WEL [8]. The speed of sound profile to be used for both site locations was calculated from measurements from location C1-1 in September and is shown in Figure B-2.

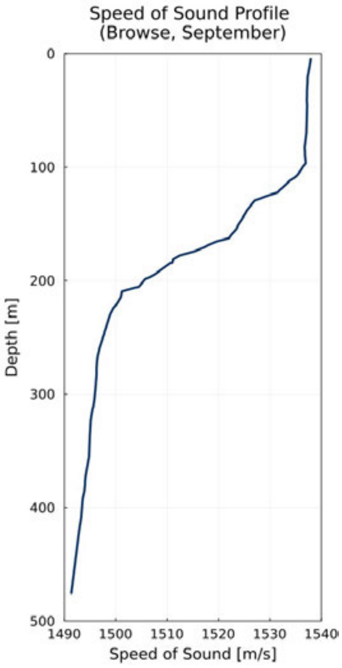


Figure B-2: Representative Speed of Sound Profile

B.1.1.3 Seabed Conditions

The seabed conditions, as stated in Section 2.2, vary for each site location. The seabed geo-acoustic properties for the primary seabed types was selected from various sources, benchmarked, and the parameters that were used are presented in Table B-2, which also states the likewise acoustic parameters for water.

Table B-2: Seabed Conditions

Material	Density [kg/m^3]	Compression Waves		Shear Waves	
		Velocity [m/s]	Attenuation [dB/λ]	Velocity [m/s]	Attenuation [dB/λ]
Water[1]	1000	1500	0	0	0
Sand[1]	1500	1700	0.7	0	0
Limestone[1, 2]	2200	2600	0.1	1400	0.2
Limestone (Equivalent Fluid)[4]	2400	1350	14	0	0

Notes:
1. Sourced from [5]
2. Alternative name for limestone being cemented calcarenite
3. Sourced from [1]

B.1.2 LF Cetacean Frequency Weighting

B.1.2.1 SEL LF Cetacean Frequency Weighting

In order to calculate the SEL, frequency weighting was approximately included to model a LF cetacean hearing response. The frequency weighting for a LF cetacean is shown in Figure B-3 and are based on Table ES2 in [7].

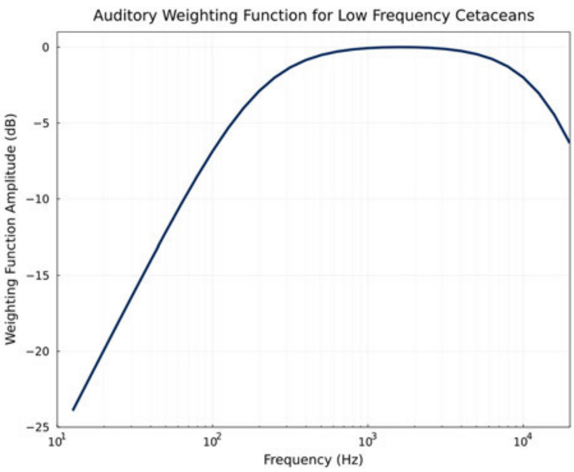


Figure B-3: Auditory Weighting Functions for Low Frequency Cetaceans

B.1.3 Modelling Assumptions

B.1.3.1 TRB

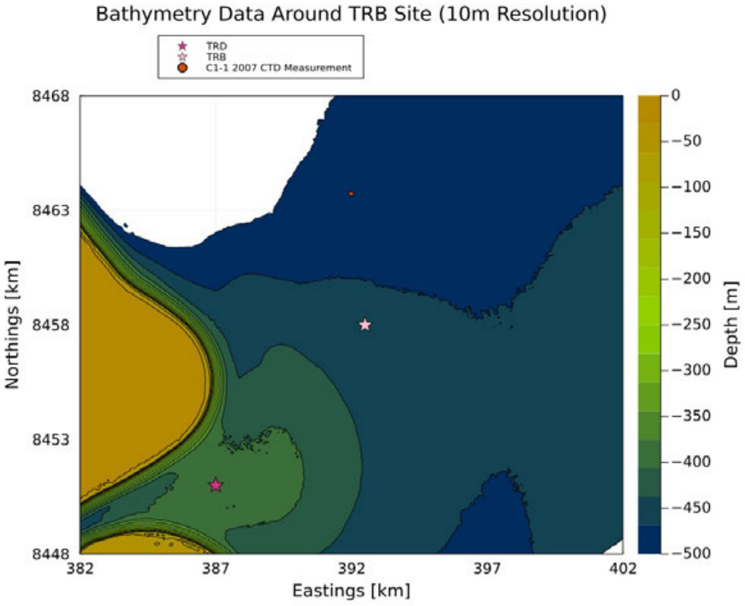
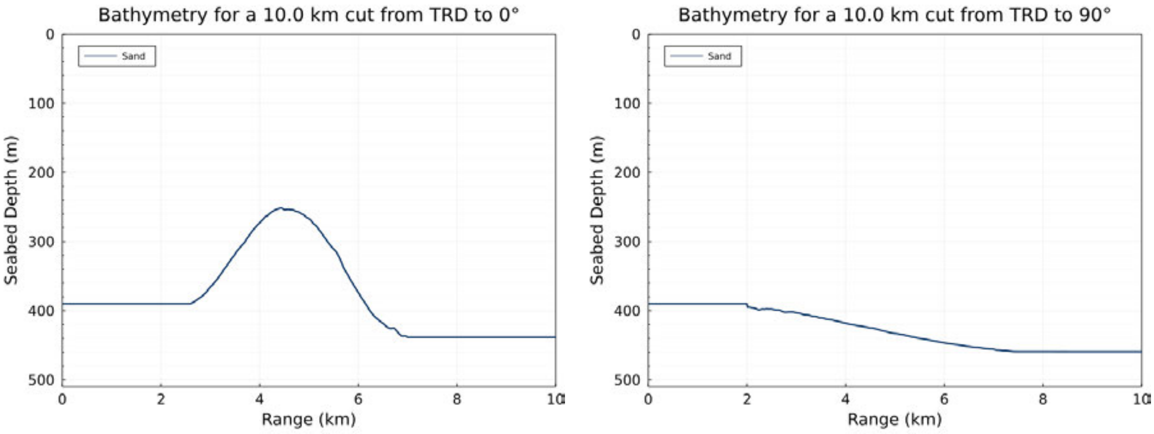


Figure B-4: Bathymetry Around TRB

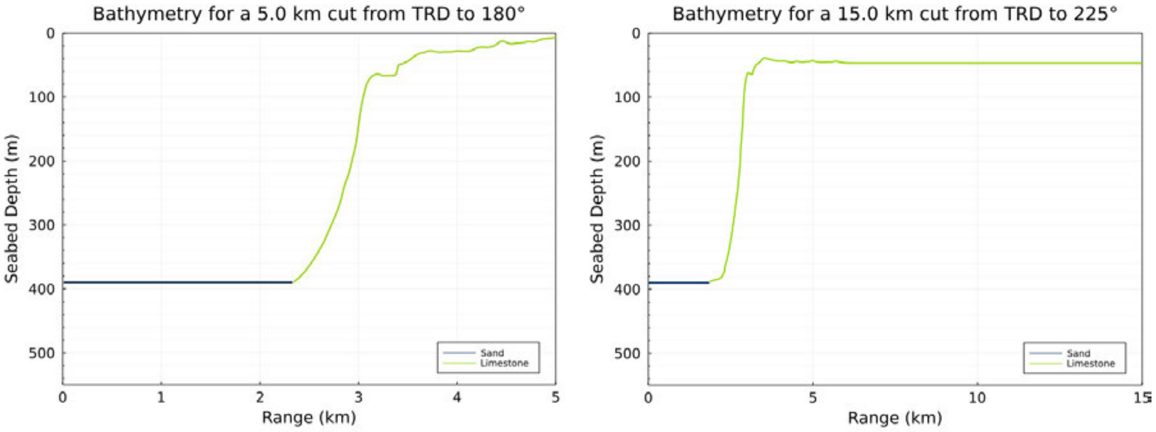
The benchmarking work detailed in Section 3 indicated that the sound levels associated with operation at TRB site would be minimal, as a result of the deep water location and a relatively small sloped sand seabed. As such, it was reasonable to model the underwater noise for a site on a uniform sandy seabed. As a result, only one azimuth was required to represent the full-field of underwater noise surrounding TRB.

B.1.3.2 TRD

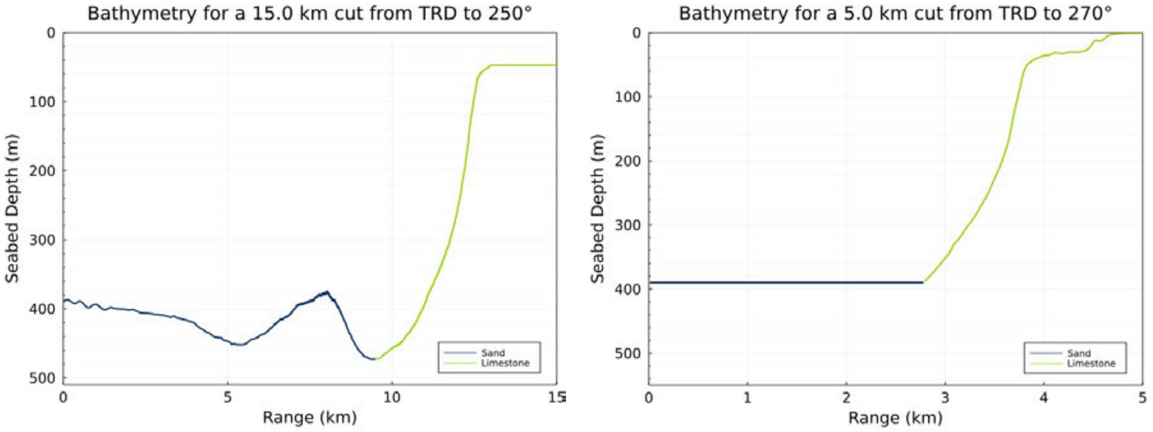
Due to the varying seabed type and bathymetry, multiple azimuths had to be considered in order to representatively model the underwater noise surrounding TRD. The selected azimuths (shown in Figure 2, in Section 2) were used to interpolate between all azimuths to generate a 3D sound level field. Figure B-5 presents the bathymetry for each cross-section, with seabed type illustrated.



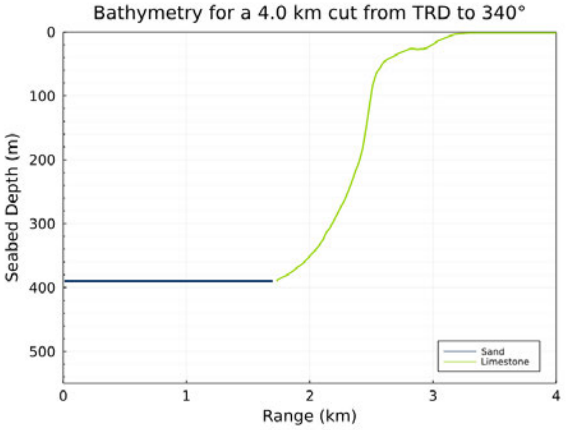
(a) Depth Profile for θ = 0° (b) Depth Profile for θ = 90°



(c) Depth Profile for θ = 180° (d) Depth Profile for θ = 225°



(e) Depth Profile for θ = 250° (f) Depth Profile for θ = 270°



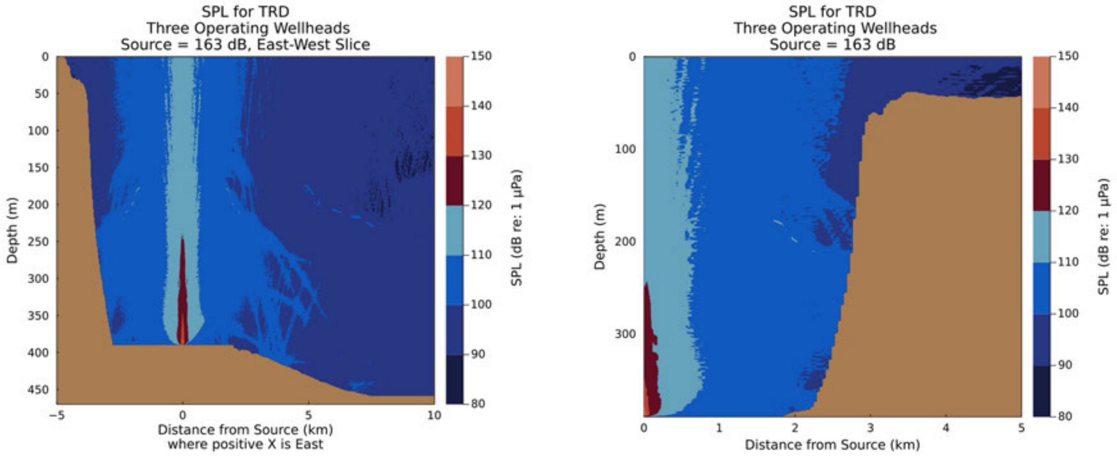
(g) Depth Profile for θ = 340°

Figure B-5: Bathymetry Depth Profiles for TRD

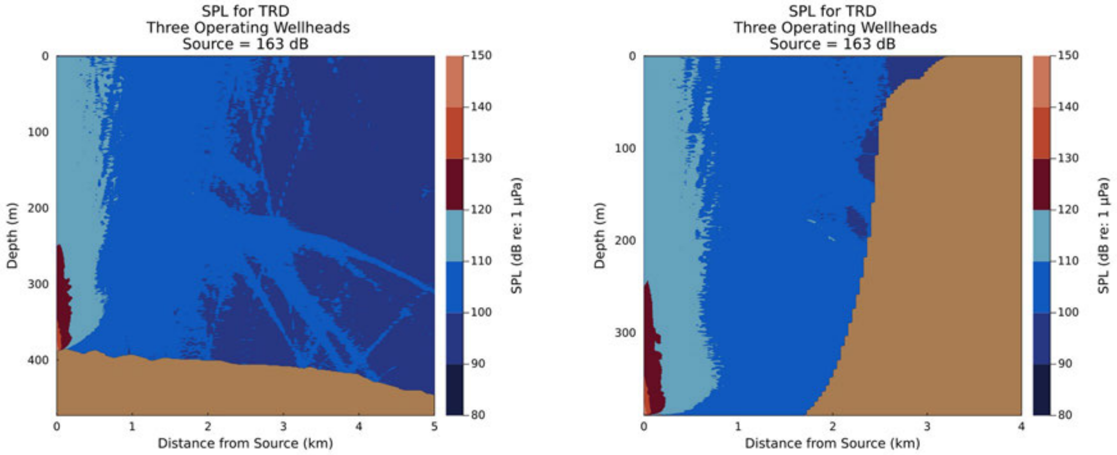
Appendix C TRD Additional Results

C.1 Elevation View (Directly Above Source) SPL & SEL Maps

C.1.1 SPL Maps

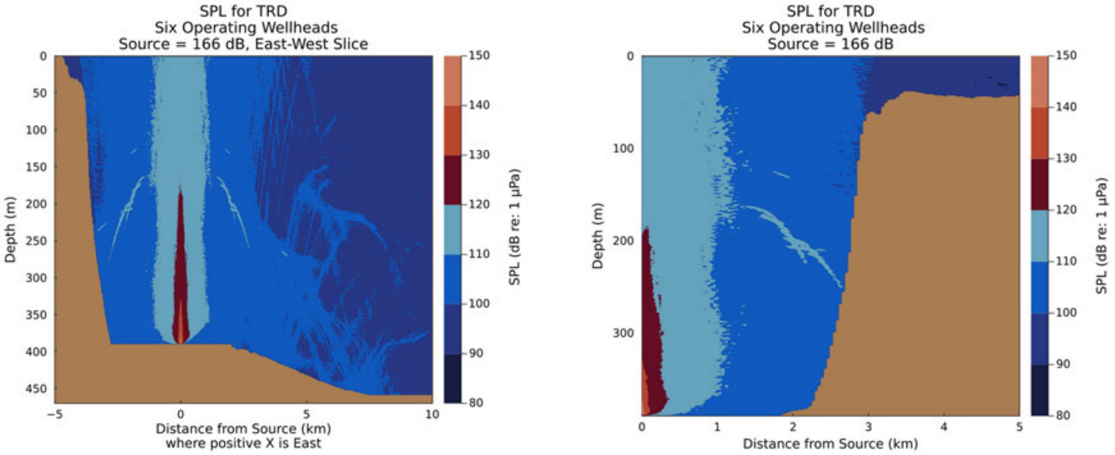


(a) East-West Slice (b) 225° Heading



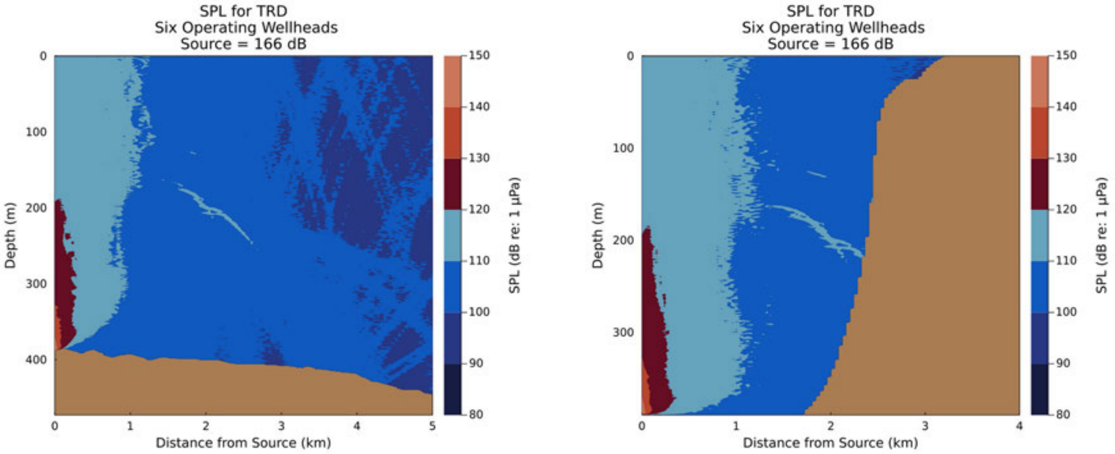
(c) 250° Heading (Through Canyon) (d) 340° Heading

Figure C-1: Additional Elevation View SPL Maps [dB re 1µPa] during TRD Scenario #1 Three Operating Wellheads



(a) East-West Slice

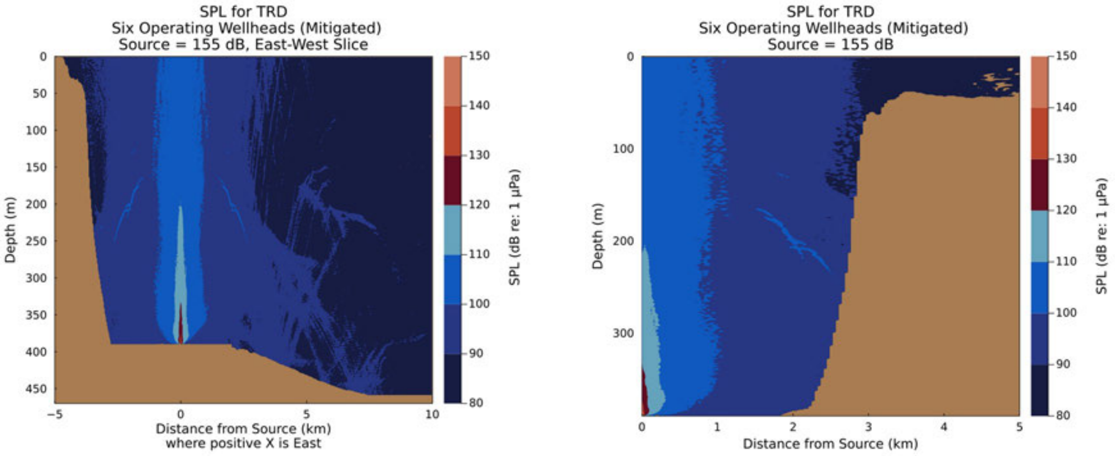
(b) 225° Heading



(c) 250° Heading (Through Canyon)

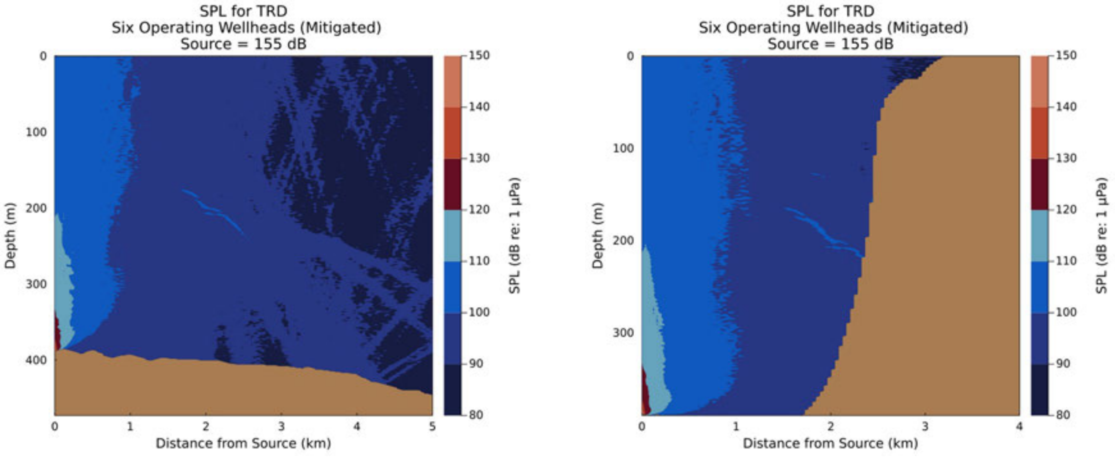
(d) 340° Heading

Figure C-2: Additional Elevation View SPL Maps [dB re 1μPa] during TRD Scenario #2 Six Operating Wellheads



(a) East-West Slice

(b) 225° Heading

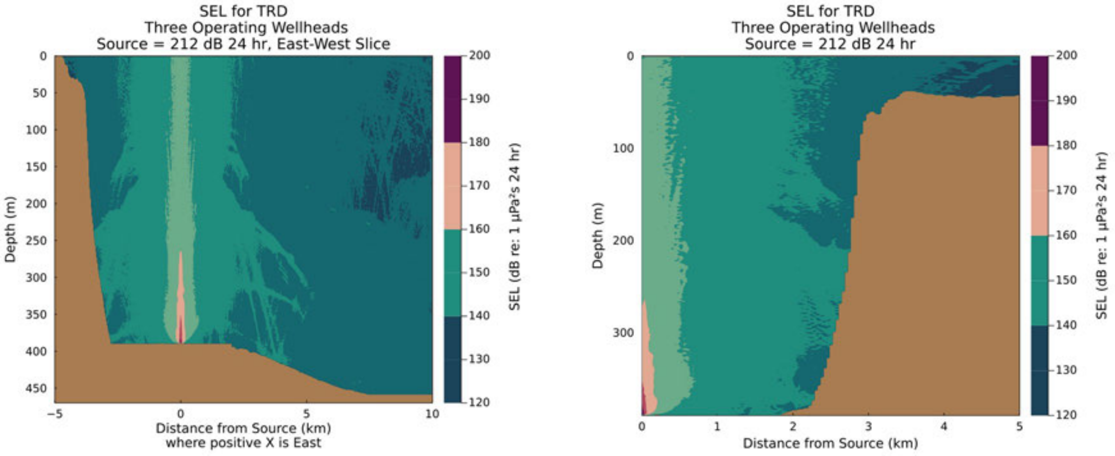


(c) 250° Heading (Through Canyon)

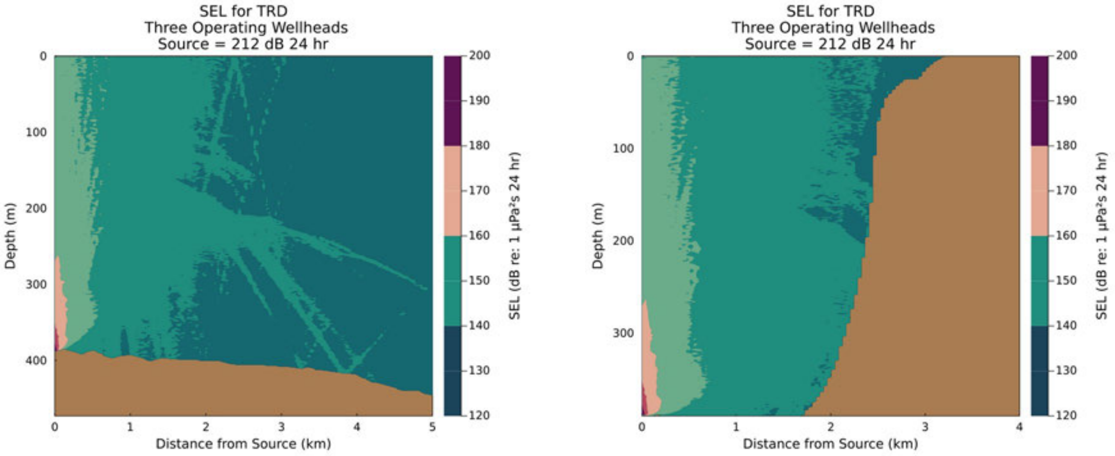
(d) 340° Heading

Figure C-3: Additional Elevation View SPL Maps [dB re 1μPa] during TRD Scenario #3 Six Operating Wellheads (Mitigated)

C.1.2 SEL Maps

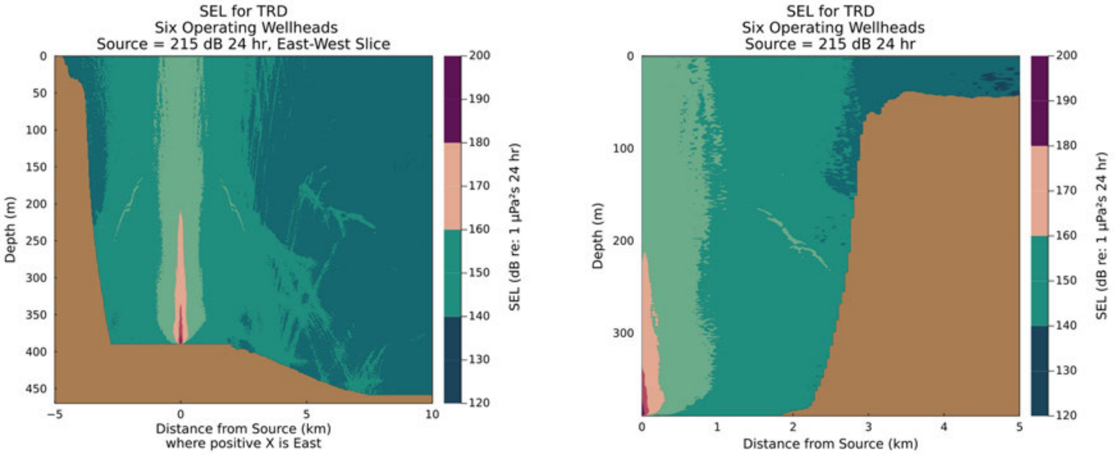


(a) East-West Slice (b) 225° Heading

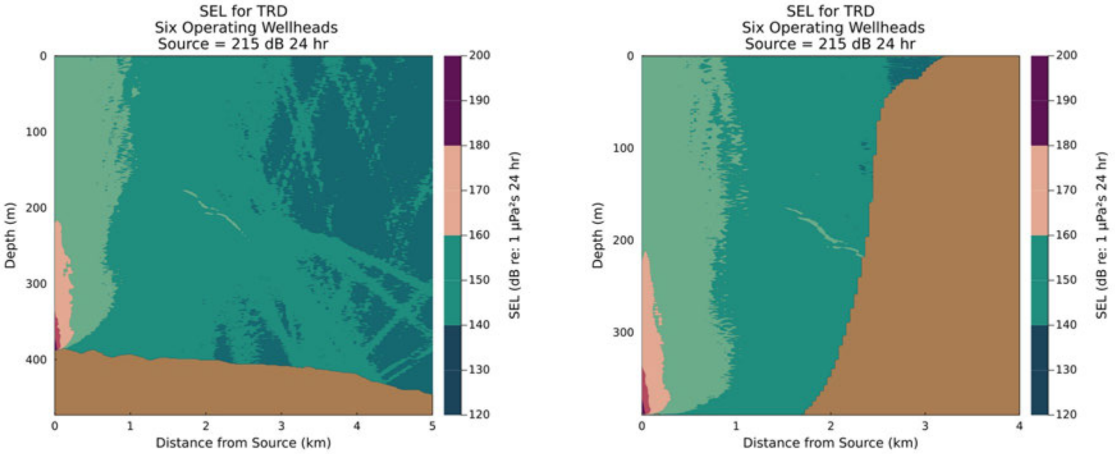


(c) 250° Heading (Through Canyon) (d) 340° Heading

Figure C-4: Additional Elevation View SEL Map [dB re 1µPa^{2}s 24 hr] during TRD Scenario #1 Three Operating Wellheads

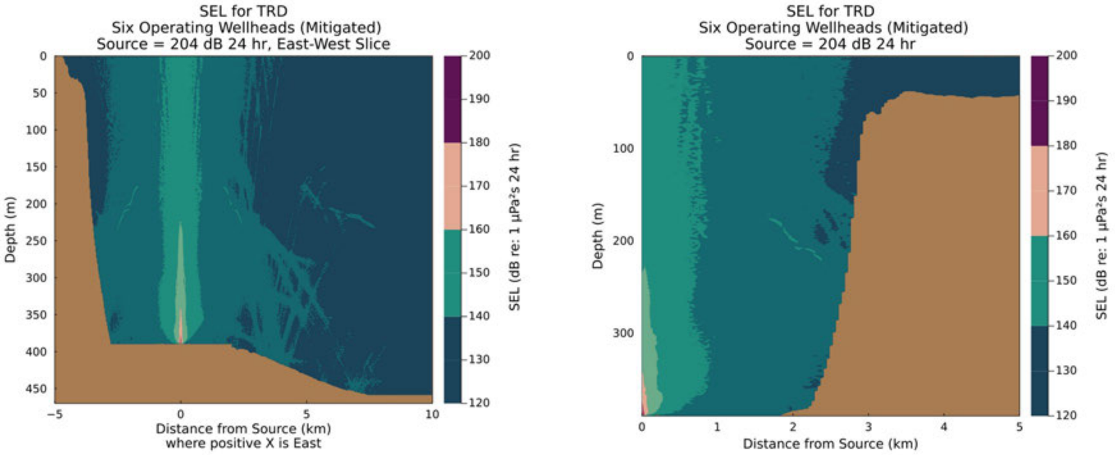


(a) East-West Slice (b) 225° Heading



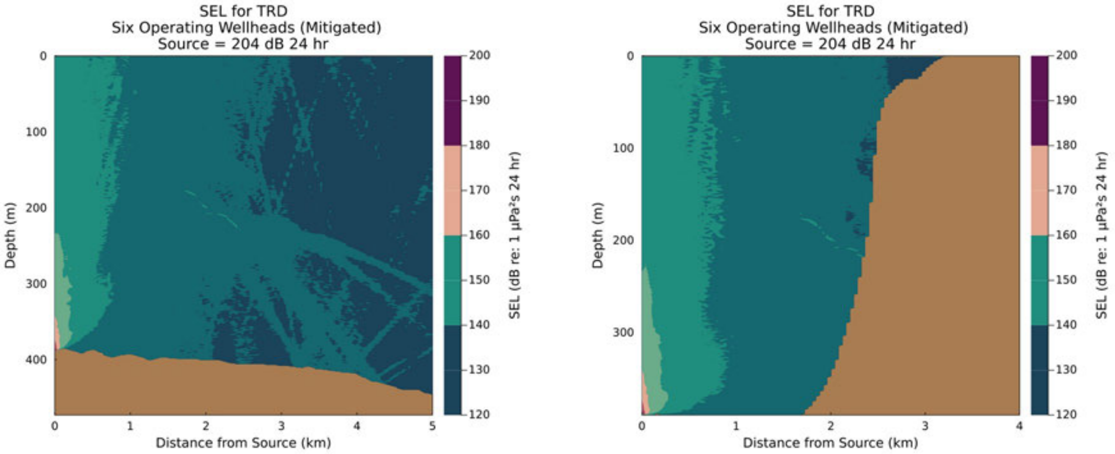
(c) 250° Heading (Through Canyon) (d) 340° Heading

Figure C-5: Additional Elevation View SEL Map [dB re 1µPa^{2}s 24 hr] during TRD Scenario #2 Six Operating Wellheads



(a) East-West Slice

(b) 225° Heading



(c) 250° Heading (Through Canyon)

(d) 340° Heading

Figure C-6: Additional Elevation View SEL Map [dB re 1µPa^{2}s 24 hr] during TRD Scenario #1 Six Operating Wellheads (Mitigated)

Appendix D Model Benchmarking

D.1 Elastic Range-Dependent Seabed Benchmarking

D.1.1 KRAKENC Benchmarking

AMOG validated the setup and inputs of its range-dependent version of KRAKENC against data published for noise transmission over a flat elastic seabed, in a shallow water environment by Koessler et al. [18]. The data presented in the benchmarking paper validated the feasibility of KRAKENC, in the range-dependent mode, against results from SCOOTER, a wave-number integration model. SCOOTER is considered the benchmark model for noise modelling of noise over flat, elastic seabeds, and the authors were able to match the results of KRAKENC with SCOOTER. An elastic seabed was selected for benchmarking as it is more difficult to model than a sandy seabed.

The results presented in the benchmarking of KRAKENC by Koessler et al. [5] demonstrated the feasibility of KRAKENC to be expanded to range-dependent modelling of noise, over steep, elastic seabeds. As no such benchmarking data exists at the time of writing, AMOG was able to verify their range-dependent KRAKENC model against the validated range-dependent models presented in [5], for low frequencies of between 2 – 200 Hz. This validated range-dependent model was then expanded for noise modelling over the non-flat TRD site. Two examples of the benchmarking results are included. Figure D-1 provides a benchmarked transmission loss comparison, at a constant water depth, for range-dependent KRAKENC against SCOOTER while figure D-2 compares the full field transmission loss for a single frequency.

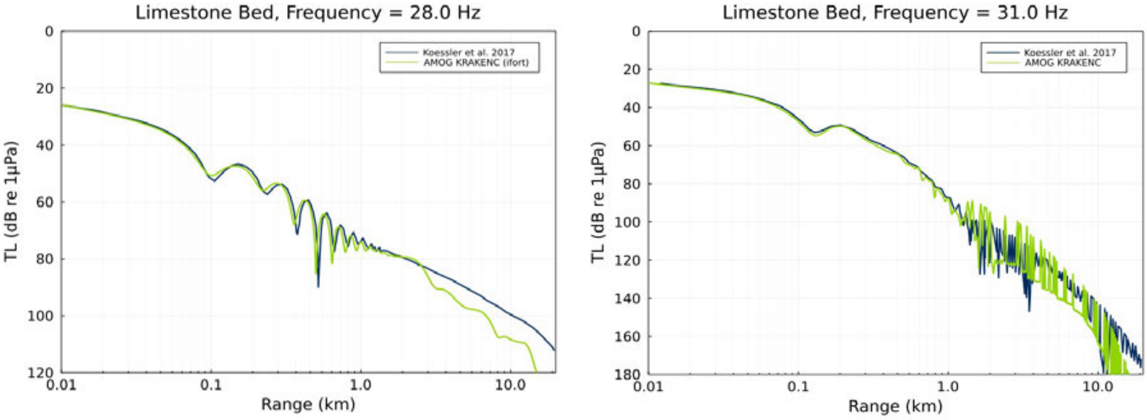


Figure D-1: Validation of AMOG range-dependent KRAKENC vs SCOOTER data [5] for elastic seabeds (right).

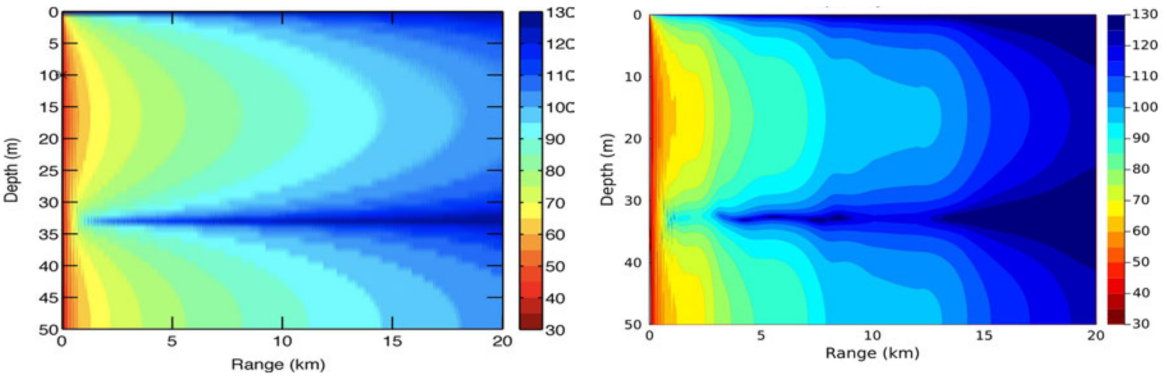


Figure D-2: Validation of KRAKENC range-dependent model (left) with SCOOTER data [5] for elastic seabeds (right).

The transmission loss at a single point in the domain, at a depth of 30 m and range of 1 km, was also compared to validate AMOG's range-dependent KRAKENC with the SCOOTER data from the benchmarking paper [5]. AMOG's range-dependent KRAKENC was found to be within 3 dB, the low-frequency ranges between 2-200 Hz, as presented in table D-1.

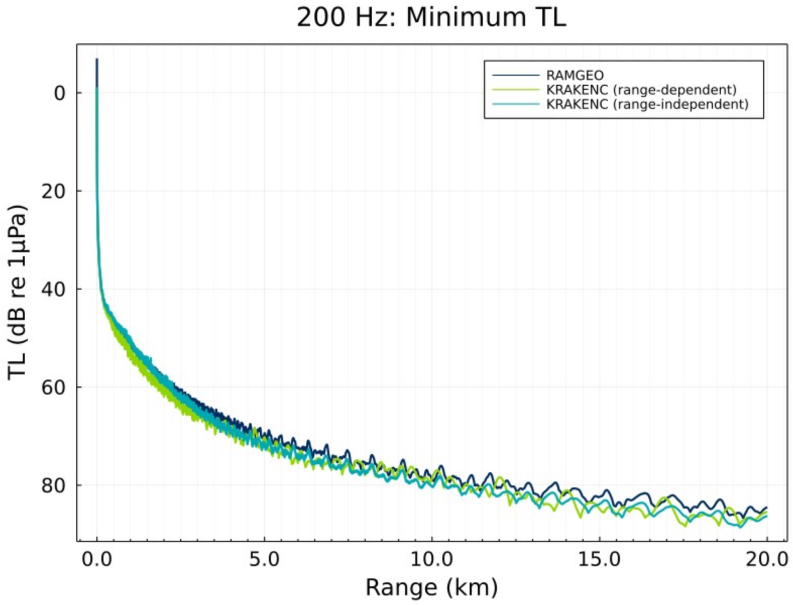
Table D-1: Point Transmission Loss Comparison between KRAKENC and SCOOTER [5]; depth of 30 m and range of 1 km, for frequencies between 2-200 Hz.

Frequency [Hz]	Transmission Loss [dB re 1 μPa]	
	Benchmark, Figure 4 from [5]	AMOG KRAKENC (Range-dependent)
2	93.1	90.2
28	75.6	74.0
31	87.5	86.8
200	59.4	56.9

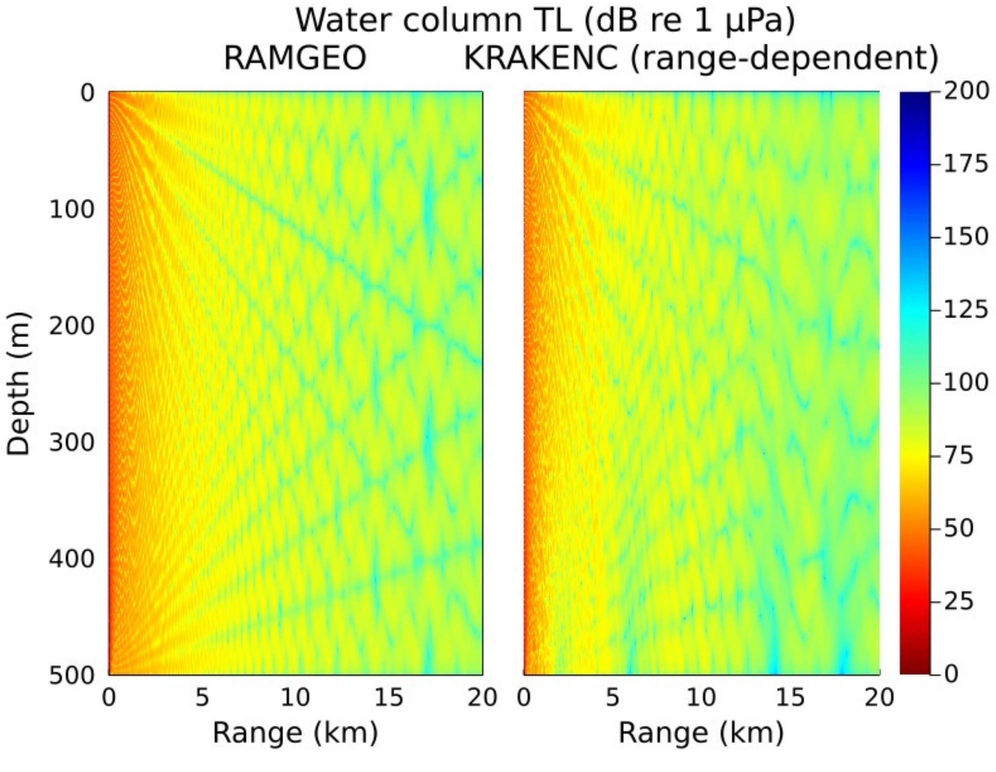
D.1.2 RAMGEO Validation

The benchmarking paper for low-frequency, noise modelling over elastic seabeds in shallow water [5], described in the previous section, also included benchmarking for RAMSGEO. The authors were able to prove that for frequencies of < 100 Hz, the RAM code was consistent with noise transmission for both KRAKENC and SCOOTER. RAMSGEO is a version of RAM which is capable of representing elastic seabeds. AMOG used RAMGEO, a version of RAM where an elastic seabed is modelled as a fluid, for simplicity. The two versions of the RAM noise models are otherwise identical.

AMOG conducted their own case-specific benchmarking of RAMGEO, for noise transmission over an elastic seabed for water depths similar to those for the TRD and TRB sites. RAMGEO was validated against the validated KRAKENC model for noise transmission for frequencies between 2 – 2000 Hz. RAMGEO was unable to produce valid noise transmission below 100 Hz, which is consistent with results presented in [5]. The results of the validated RAMGEO setup for elastic seabeds is presented in figures D-3 and D-4, for 200 Hz and 2000 Hz respectively. These plots include minimum transmission loss (TL) results from the range-independent model for KRAKENC, which is based on the setup described in [5].

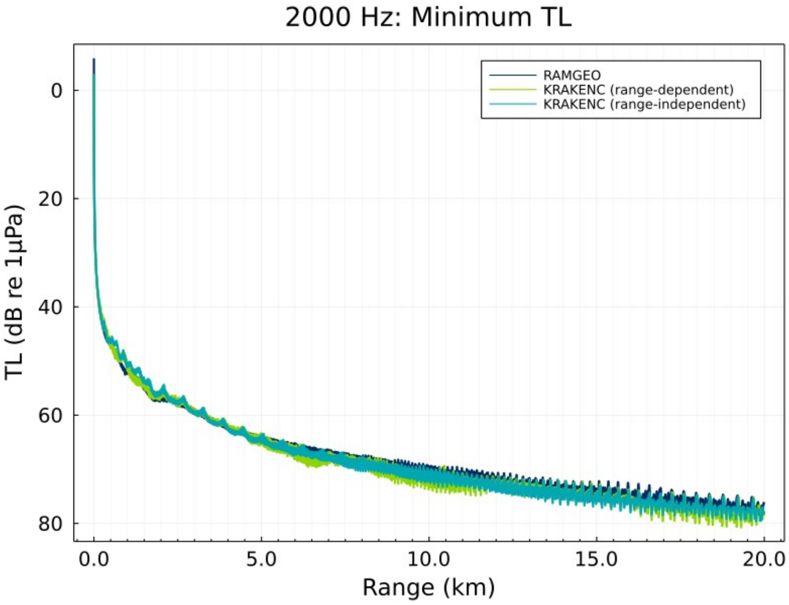


(a) Minimum transmission comparison.

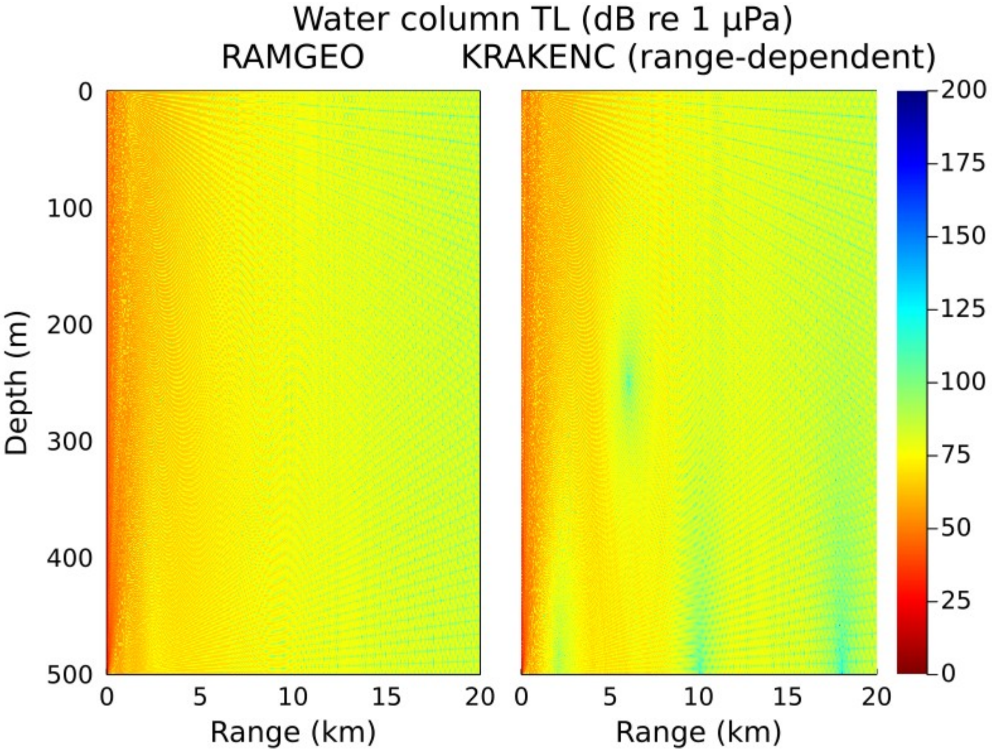


(b) 2D water column transmission loss comparison.

Figure D-3: Validation of RAMGEO with KRAKENC for elastic seabeds for 200 Hz.



(a) Minimum transmission comparison.



(b) 2D water column transmission loss comparison.

Figure D-4: Validation of RAMGEO with KRAKENC for elastic seabeds for 2000 Hz.